# NUCLEAR ENERGY

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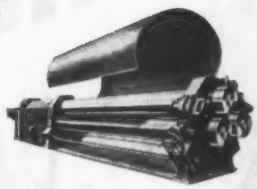

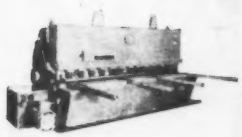

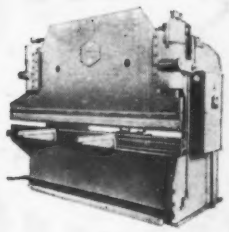

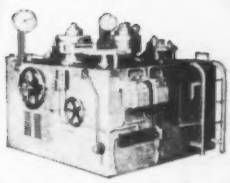

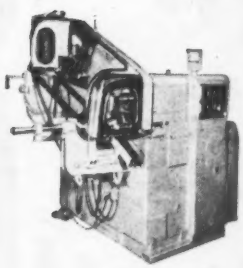


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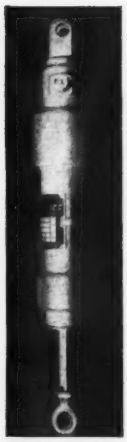

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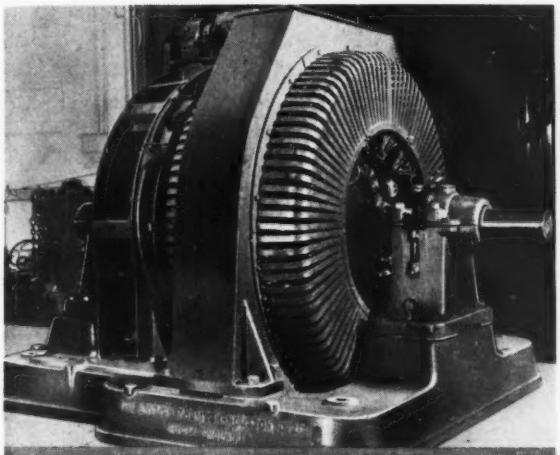

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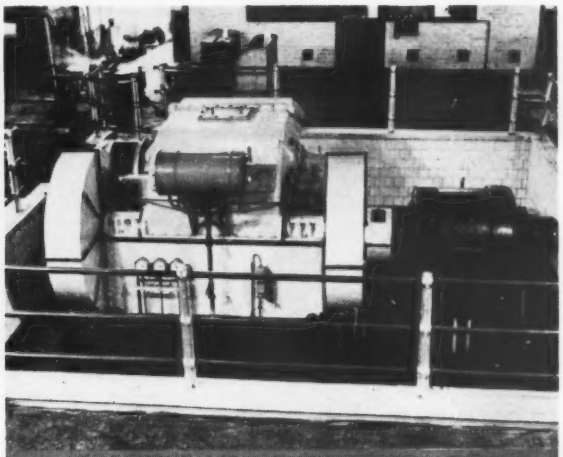

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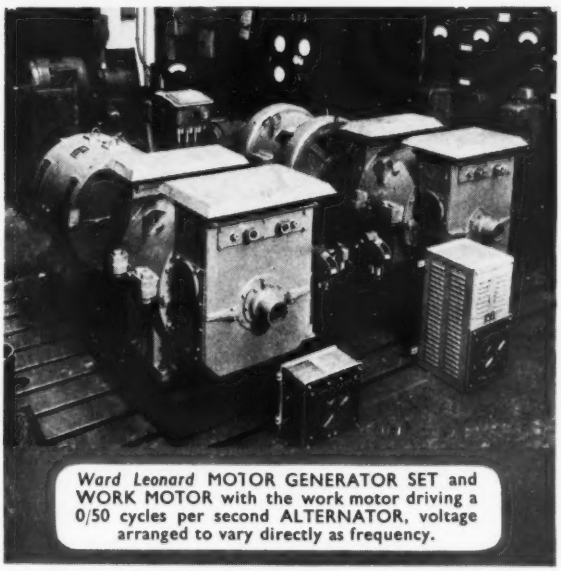

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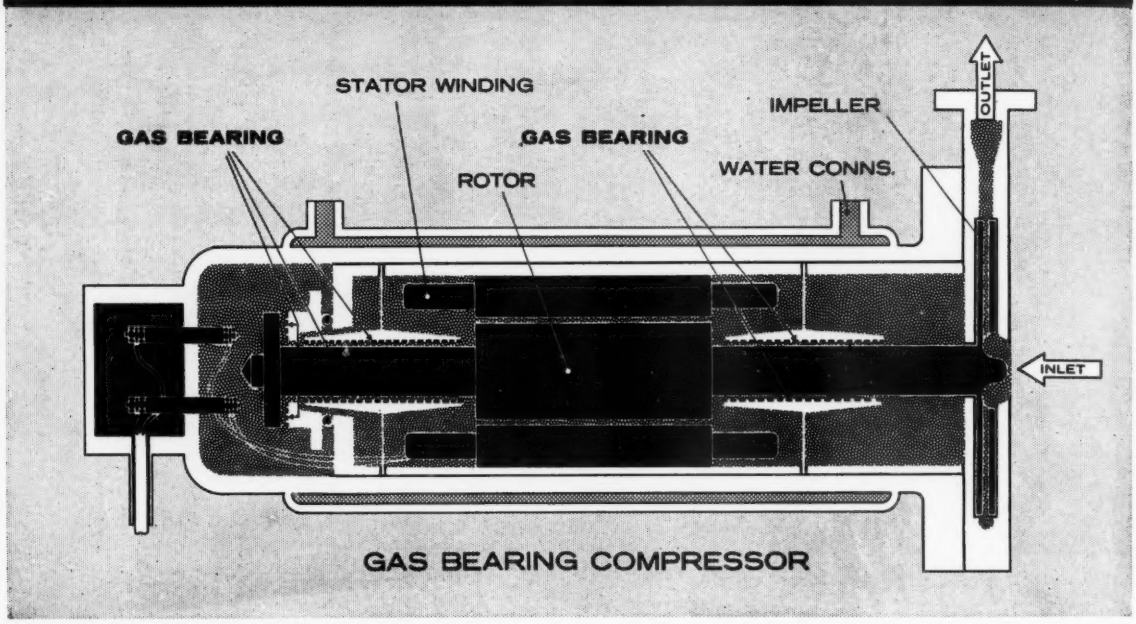


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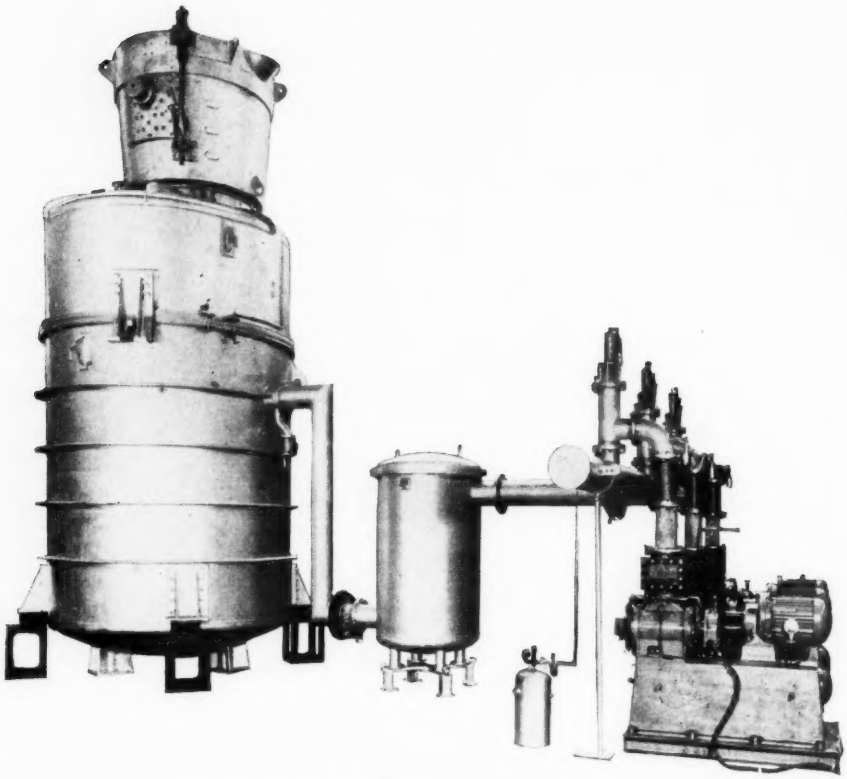

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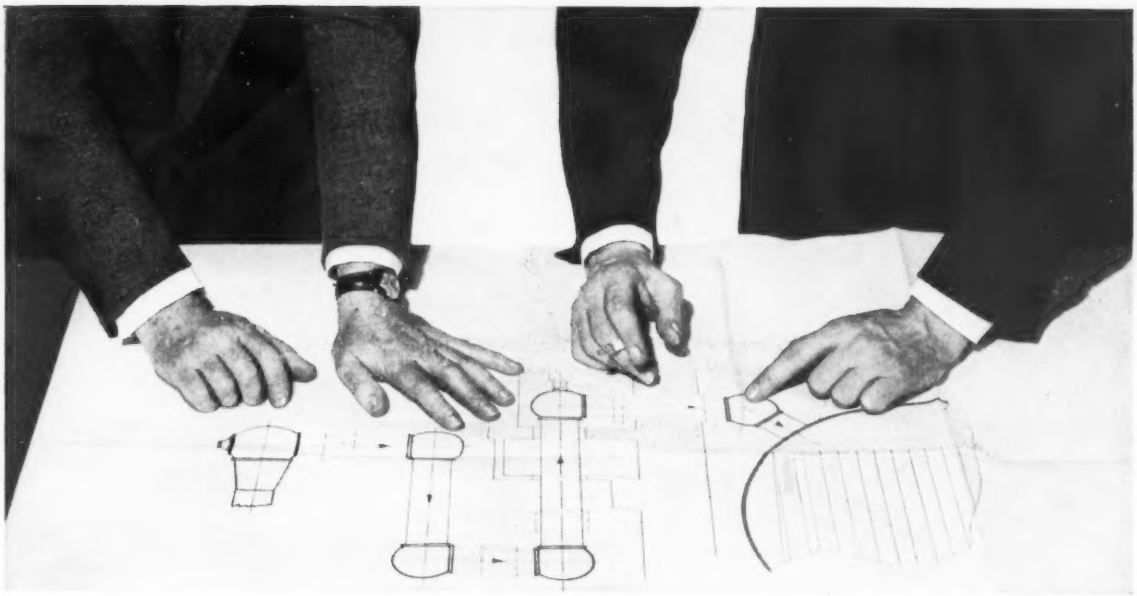

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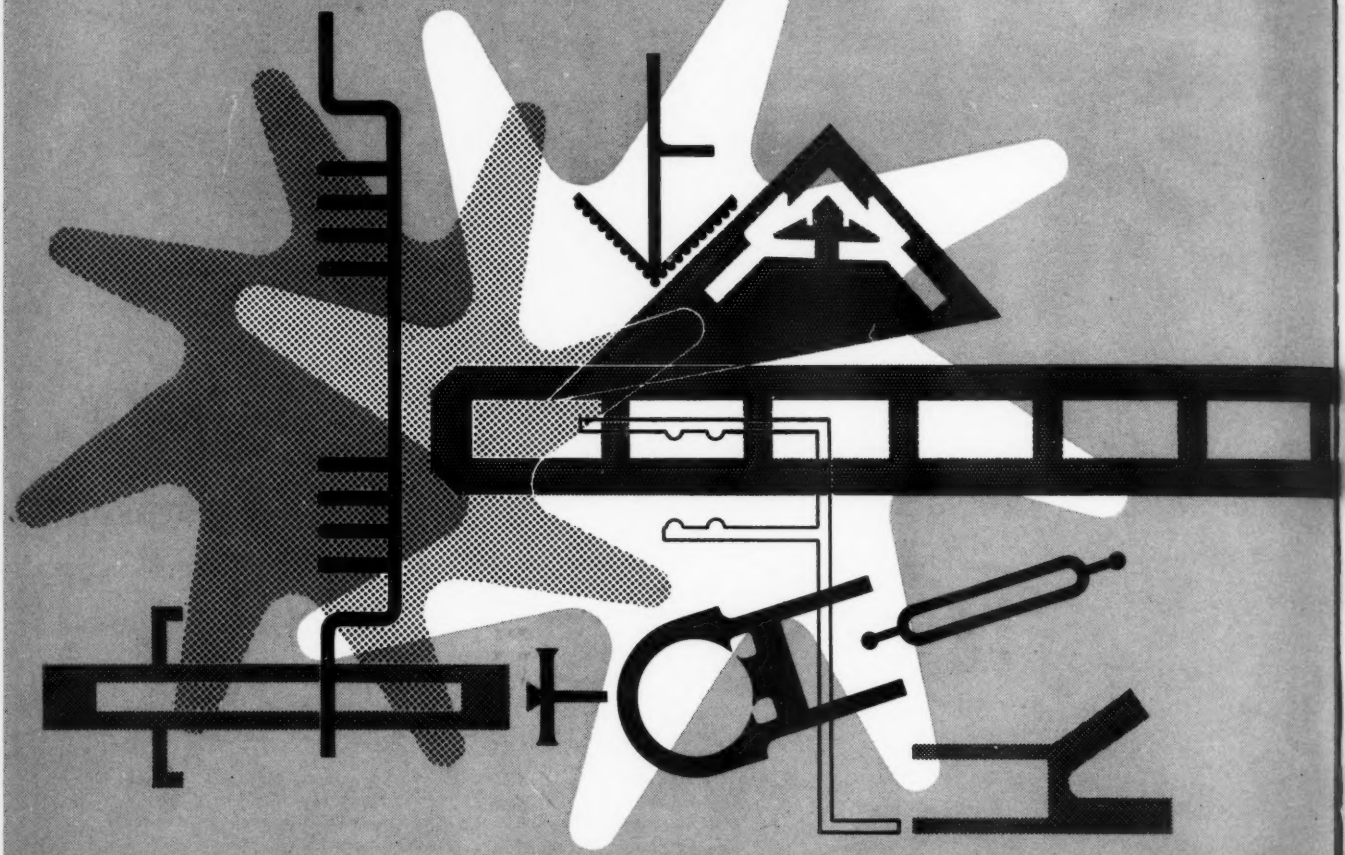

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**APRIL, 1960**


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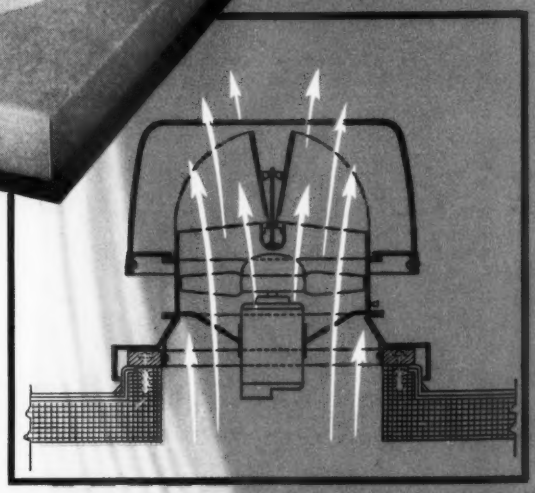

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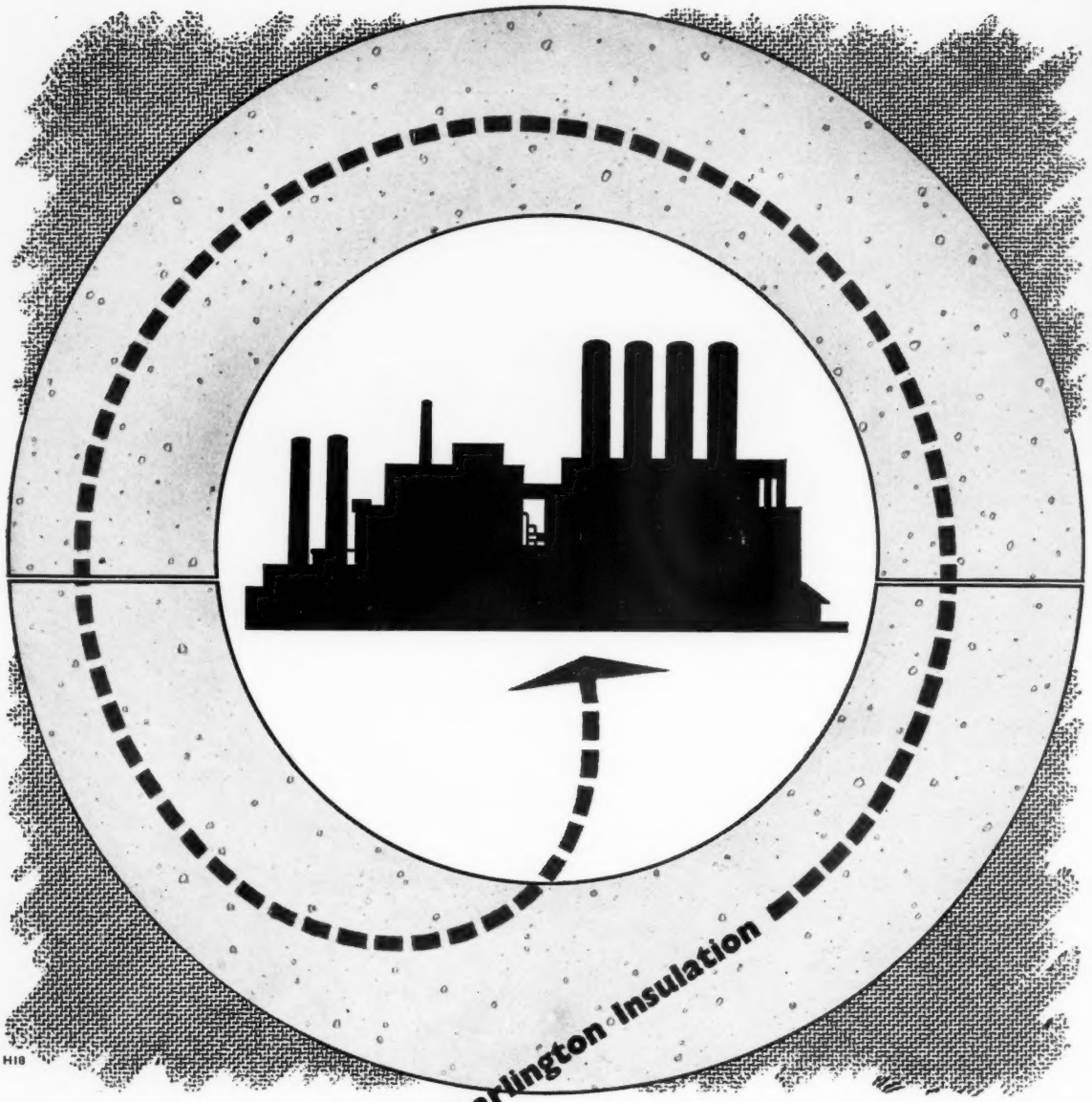


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*Headquarters and research centre of CERN at Meyrin, near Geneva. The 25 GeV proton synchrotron and ancillary buildings and laboratories are seen to the right*

# CERN's 25 GeV PROTON SYNCHROTRON

## Notable International Project

THE possession of anything which can be described as the largest longest, smallest or fastest is, and always has been, of a transitory nature. Use a superlative and sooner or later it has to be relinquished. Somebody else comes along with something larger, longer, smaller and faster.

Shortly, the 25 GeV proton synchrotron situated at the headquarters of CERN, Geneva, will lose its present distinction as being the world's largest particle accelerator, which it has held since only last November, when it was first put into operation. The Americans have built a slightly more powerful machine at the Brookhaven National Laboratory, Long Island which is due to start functioning any time now.

There is one consolation for CERN. In two to three years time the American machine will be surpassed by the 50 GeV alternating gradient proton synchrotron the Russians are to bring into operation at Leningrad.

In spite of it being overshadowed in this way, the CERN proton synchrotron is, and will remain, a notable achievement. It is, for one thing, nearly three times as powerful as the world's previous largest accelerator, the 10 GeV synchro-phasotron at Dubna, Russia. It is incidentally, four times as powerful as the NIMROD, the 7 GeV proton synchrotron being built at Harwell and described in NUCLEAR ENERGY, February, 1960. Although known as a 25 GeV proton synchrotron, particles have in fact been accelerated at energies of up to 28.3 GeV.

### 13 Nations Contribute

Perhaps even more noteworthy about the CERN machine is that it was designed and built and is owned and operated on an entirely truly international basis.

The European Organization for Nuclear Research, or, as it is more generally known, CERN, which are the initials of the Conseil Europeen pour la Recherche Nucléaire, is operated through the co-operation of 13 different countries, and it was established solely for carrying out fundamental nuclear physics research.

The countries concerned are Austria, Belgium, Denmark, France, the German Federal Republic, Greece, Italy, Netherlands, Norway, Sweden, Switzerland, the United Kingdom, and Yugoslavia. Each one makes a financial contribution in proportion to its national income and each is represented on the governing Council by two delegates.

The headquarters of CERN are at Meyrin, near Geneva, where besides the 25 GeV proton synchrotron there is a 600 MeV synchro-cyclotron, which went into operation in 1957, and various laboratories and other smaller research equipment.

The function of a proton synchrotron is to give protons—the nuclei of hydrogen atoms—the very high kinetic energy needed if they are to be used to break up other atomic nuclei. The protons travel round the synchrotron at a velocity just below that of light, which is 2,200 miles (3,600 km)/sec. As they cannot be accelerated any faster than this any energy which is added to them is converted, as according to Einstein's law, energy=mass $\times$ the square of

the velocity of light ($E=mc^2$), into mass. The protons accelerated in the Geneva machine do in fact increase their mass 25 times. These fast-moving, heavy, easily penetrable particles when bombarded on to an atom target give rise to events which can be studied to provide valuable scientific information.

## Pre-Acceleration

The protons reach their maximum energy in stages. They are produced from atoms of hydrogen gas by ion source, from where they enter a Cockcroft-Walton machine to be accelerated up to 500,000 electron-volt (50 KeV). After this they enter a linear accelerator and in successive stages their energy is raised to 50m. electronvolt, or the equivalent of an injection speed of about one-third the velocity of light.

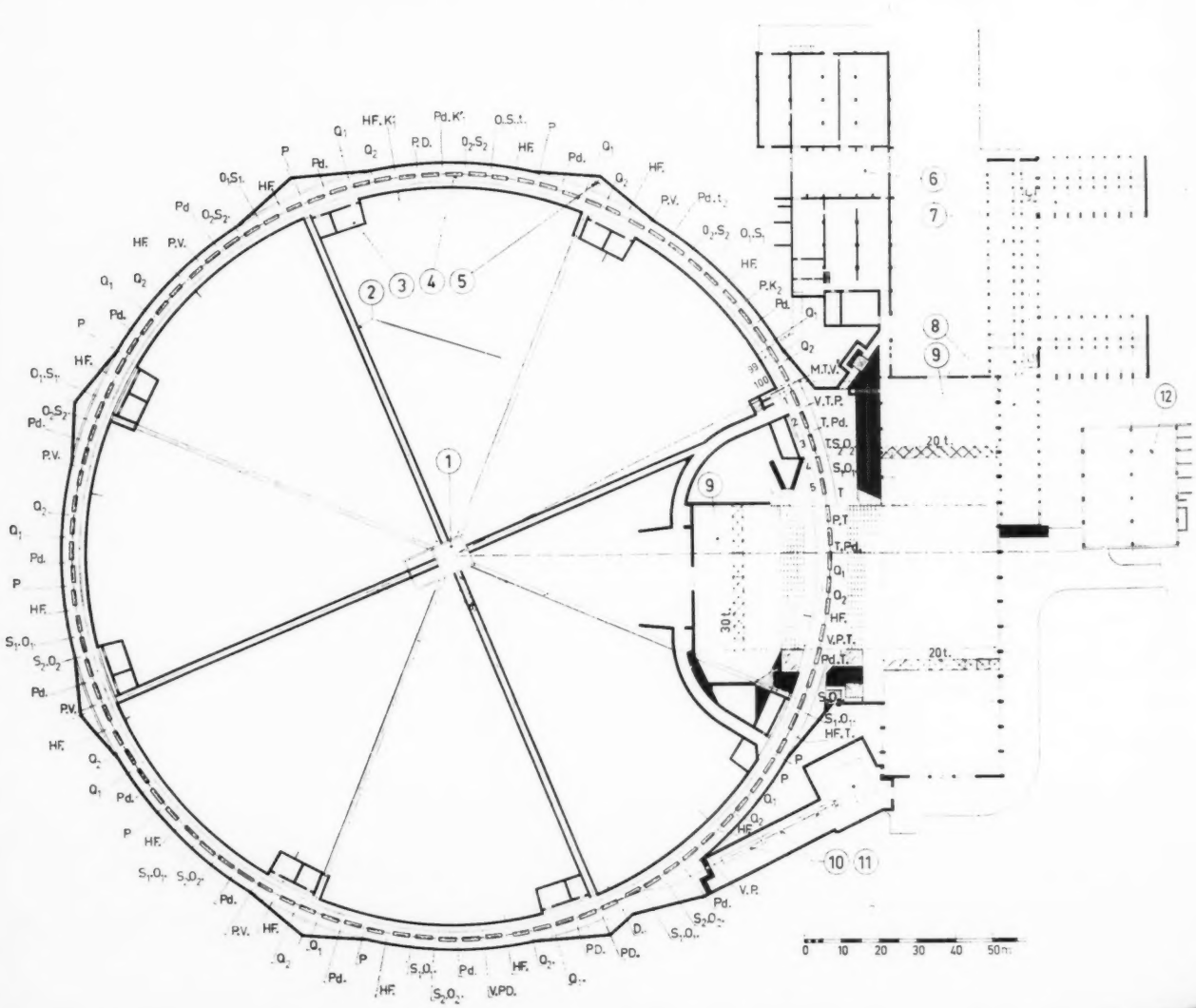
They are now ready to enter the synchrotron proper, the 656 ft diameter (200 m) ring chamber which is partly below ground level and from the air, being covered with soil, gives the impression of being a giant wheel shaped barrow. The particles are accelerated here by means of electric fields distributed in 16 locations round the ring. These are called accelerating cavities and operate on a radio frequency system.

In one second the particles travel round the synchrotron 480,000 times. And in that second they reach up to 99.94 per cent. the speed of light, at which point their energy is about 25,000m. electronvolt.

The particles travel in a vacuum chamber with a cross section of 5.6 in. × 2.8 in. (14 cm × 7 cm). One hundred magnet units keep the particles within this chamber and also focused on their 656 ft diameter orbit round the synchrotron. To help maintain this focusing system pick-up electrodes are used to ascertain the position of the proton beam in relation to the walls of chamber—a remarkable achievement in view of the enormous speed at which the particles are moving.

The beam of high energy particles can be used in one of several ways. It can, for instance, be used to strike a target placed inside the vacuum chamber itself. The fragments of the atoms disintegrated in impact, in addition to any new particles created

**Plan of the proton synchrotron. Key: 1=central survey station and radio frequency control station; 2=radial tunnels; 3=radio frequency equipment room; 4=one of the 100 magnet units; 5=survey point; 6=main alternator; 7=laboratories; 8=main control room; 9=experimental halls; 10=linear accelerator; 11=500 keV generator; 12=generator building, south, supplying power to experimental apparatus in 9**
**HF=accelerating cavity; T=target; M=ejection magnet; D=permanent electrostatic deflector for beam injection; PD=pulsed electrostatic deflector; P-Pd=pick-up electrode; V-V'=pumping valves; $K_1$-$K_2$=double ejection magnet; $K'_1$=simple ejection magnet; $t_1$-$t_2$=ejection targets; $O_1$-$O_2$=quadrupole lenses; $S_{1'2}$-$O_{1'2}$=sextupole and octupole lenses**



by the conversion of energy into mass, are then observed and studied by means of photographic emulsions and other techniques.

Alternatively, the beam can be ejected at a given point and directed into one of two of the large experimental halls in which counters and bubble and cloud chambers are installed.

Because of the hazards of radiation strong baryte concrete shielding has been installed wherever necessary and access to the machine is prohibited while it is being operated.

## Change of Plan

Originally CERN had planned to build a 10 GeV proton synchrotron. When the three scientists who had been commissioned to produce a design study for this project learnt of a new idea for making cheaper and higher energy machines it was decided to abandon the original project. It seemed that a 30 GeV machine might be built for the same cost as a 10 GeV synchrotron.

The alternating gradient principle employed in the CERN machine has been known for many years. In the conventional synchrotron the focusing of the circulating particles is achieved by arranging that the magnetic field which guides the particles around a fixed radius decreases slightly with radius. The amount of focusing achieved in this way is not very great and consequently the amplitudes of the free oscillation of the particles are large and the dimensions of the magnet gap correspondingly large.

Most of the cost in the original synchrotrons is in the magnet. For example, the Russian 10 GeV synchro-phasotron magnet, which has a radius of 30.5 m, contains 35,000 tons of steel and the magnet gap is 150 cm wide and 40 cm high. The CERN GeV proton synchrotron magnet on the other hand contains only 3,400 tons of steel and has a useful aperture of 14 cm × 7 cm. It has a larger radius—100 m.

## How Weight is Reduced

Although greater focusing in the conventional machine can be obtained in the axial direction by increasing the gradient of the magnetic field, the criterion for radial stability is violated. It is the great advantage of the alternating gradient principle that the focusing of the circulating particles can, in theory, be made as strong as one wishes and the amplitudes of the oscillation of the particles as small as desired. This is achieved by alternating the sign of the gradient of the magnetic field many times around the circumference of the magnet. The net result of this stronger focusing is to reduce greatly the weight of the magnet, as achieved in the CERN machine.

The attractive advantages of the alternating gradient principle are realized at the price of greatly increased accuracy in manufacturing and aligning the magnet. Also, once the magnet is set up it must remain in place and for a 200 m diameter this presents some interesting foundation problems.

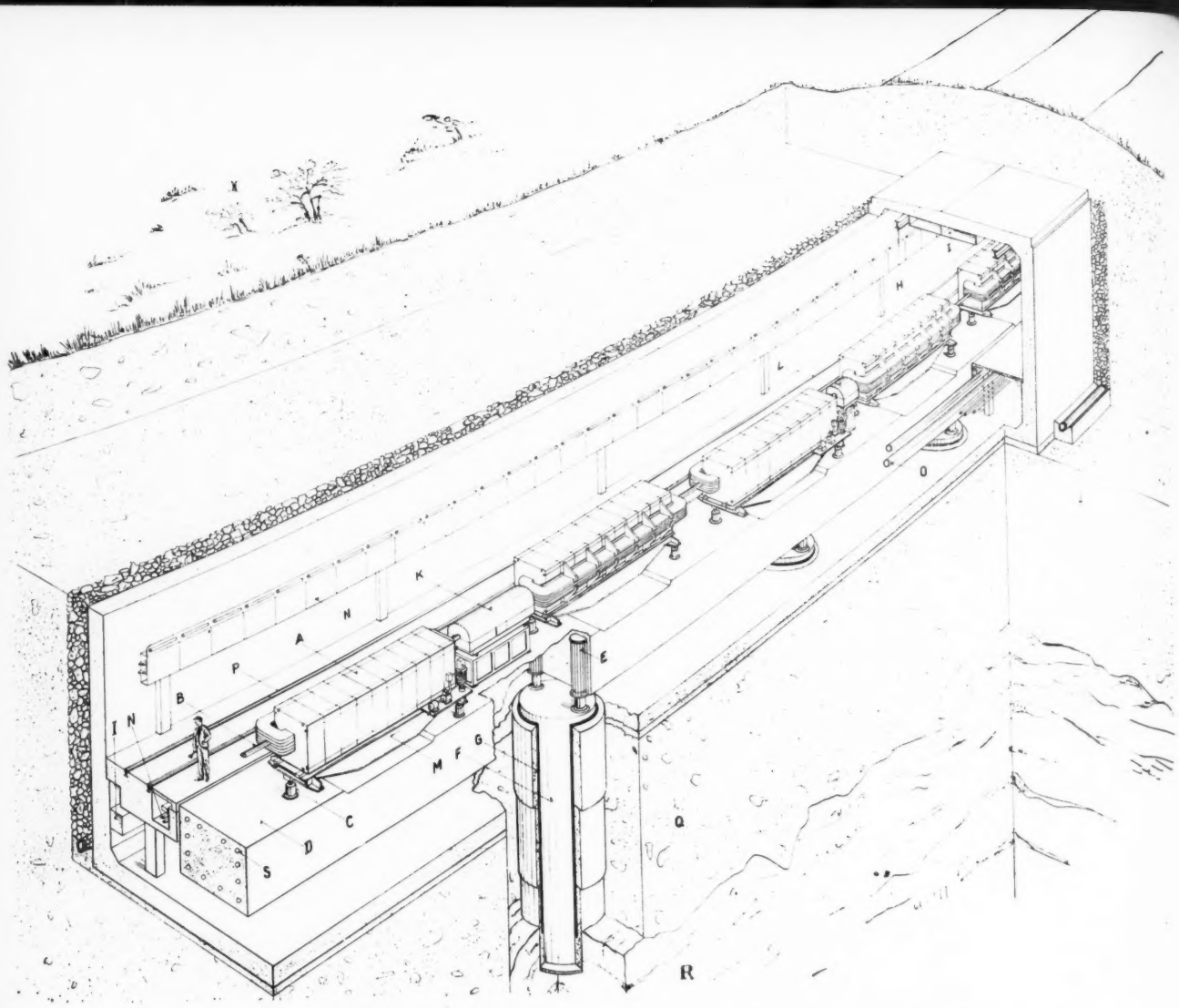
## Specification of the Synchrotron

| | |
|---|---|
| **General Data** | |
| Maximum kinetic energy at 12,000 gauss | 24.3 GeV |
| Maximum kinetic energy at 14,000 gauss | 28.3 GeV |
| Magnetic radius | 70.079 m |
| Mean radius | 100 m |
| No. of magnetic periods | 50 |
| No. of magnet units | 100 |
| Length of magnet unit | 4.30 m |
| No. of linear lenses | 10 pairs |
| No. of non-linear lenses | 20 pairs |
| **Magnet and Power Supply Data** | |
| Magnetic field at injection | 147 gauss |
| for 24.3 GeV | 12,000 gauss |
| maximum | 14,000 gauss |
| Weight of one magnet unit | 38 ton |
| Total weight of coils (aluminium) | 110 ton |
| Total weight of iron | 3,400 ton |
| Rise time to 12 Kgauss | 1 sec |
| No. of cycles/min (12 Kgauss operation) | 20 |
| Peak power to energize magnet | 34,600 kW |
| Stored energy | $10^7$ joule |
| Mean dissipated power | 1,500 kW |
| **Radio Frequency Data** | |
| Energy gain per turn | 54 KeV |
| Stable phase angle | 60° |
| No. of accelerating cavities | 16 |
| Length of cavity | 2.3 m |
| Harmonic number | 20 |
| Frequency range | 2.9—9.55 Mc/s |
| Power per cavity | 6 kW |
| **Injection Data** | |
| Injection energy | 50 ± 0.1 MeV |
| Injection field | 147 gauss |
| Length of linear accelerator | 30 m |
| RF power | 5 MW at 202.5 Mc/s during 200 μs |
| **Vacuum System Data** | |
| Vacuum chamber length | 628 m |
| section | 7 × 4 cm |
| Wall thickness | 2 mm |
| Vacuum pumps | 4 + 67 stations |
| Pressure, better than | $10^{-5}$ mm Hg |

The CERN proton synchrotron magnet is made up of 100 supposedly identical magnet units, each about 4.3 m long. The magnetic field error between these units for the same energizing current should not exceed about one part/thousand, and the units should be set up with a precision of a few parts/m. (0.3 mm in a 100 m radius).

## Temperature Controlled

The units are mounted on a free floating monolith ring of concrete 200 m in diameter and 2 m × 2 m in cross section, and the machine is built in a subterranean annular tunnel in which the temperature is controlled to within ±1°C. As a further precaution the concrete ring has steel pipes cast in it and water is passed through these to prevent any




Perspective of a ring section of the CERN proton synchrotron. A = magnet unit; B = vacuum chamber; C = screw jack; D = concrete girder independent of the building and supported by E = elastic supports; F = concrete column based on rock; G = bitumen; H = 2-ton crane; I = air-conditioning; K = accelerating cavity; L = octupole lens; M = vacuum pump; N = electrical cables; O = magnet water cooling; P = narrow gauge railroad track; Q = earth; R = rock; S = temperature regulating water pipes

part of the ring assuming a temperature different from the rest.

Another advantage of the alternating gradient principle is that the amplitude of the momentum oscillations is very much smaller than in the conventional synchrotron. Since these momentum oscillations result in radial movements of the particles which have to be contained within the width of the magnet aperture the alternating gradient synchrotron is again more economical in magnet aperture than the conventional synchrotron, in this case by a factor of about 60. Unfortunately, this improvement also involves problems arising from the much greater accuracy that is needed.

### *Distribution of Studies*

Design studies on the synchrotron were started in 1952. Theoretical studies were made at Harwell, and at the Universitetets Institut for Teoretisk Fysik, Copenhagen; magnet studies were concentrated at the Laboratoire de Radioélectricité de l'Universite, Paris; the radio frequency problems were investigated at the Institut fur Physik, Max-Planck-Institut, Heidelberg; radiation shielding at the Physikalisches Institut der Universitat, Freiburg-i.B., Germany and the general engineering problems were studied at the Chr. Michelsens Institut, Bergen, Norway. Design of the final machine was completed in 1954 and assembly of the various components took place in 1958. Testing and commissioning followed in 1959 and the machine, working at a magnetic flux density of 12,000 gauss, accelerated protons to a kinetic energy of 24.3 GeV in

## CERN's Finance

The cost of CERN's 25 GeV proton synchrotron is estimated to be about 120m. Swiss francs, or about £10m. CERN is financed by its member states, each contributing according to its national income. The percentages of the total contributions made by each of the countries are as follows:—Austria, 1.93 per cent.; Belgium, 4.15 per cent.; Denmark, 1.99 per cent.; France, 21.22 per cent.; German Federal Republic, 19.52 per cent.; Greece 1.17 per cent.; Italy, 10.09 per cent.; Netherlands, 3.85 per cent.; Norway, 1.61 per cent.; Sweden, 4.23 per cent.; Switzerland, 3.29 per cent.; United Kingdom, 25 per cent. and Yugoslavia, 1.95 per cent.

CERN'S budgets since 1955 follow (they are in millions of Swiss francs): 1955—25.1; 1956—39.6; 1957—61.8; 1958—56.5; 1959—55.2; 1960—65.

November, 1959. After making adjustments to the shape of the magnetic field so that field values of 14,000 gauss were obtained the maximum energy was increased a little later to 28.3 GeV. There was no noticeable loss of particles during the acceleration period and the intensity of the accelerated beam of protons was measured as $10^{10}$ protons/pulse. The pulse repetition rate at 25 GeV is 20/min.

Measurements so far carried out on the proton synchrotron are necessarily preliminary and incomplete. Several months will have to pass before sufficient is known about the machine to exploit it as a working physics tool.

### Probable Experiments

The experiments which will probably be carried out with the proton synchrotron will include studies on p-p-scattering, $\pi$-p-scattering, $\pi$-p interactions, scattering of K+ mesons against protons, diffractive production of $\pi$ by protons on nuclei, proton-antiproton interaction and interaction of high energy $\gamma$ rays.

### Contractors, Etc.

Consulting Engineers who worked on the project were Prof. G. Schmitter, D. Bonnard, R. Spieser, and Eng. H. Wegmann. Architects were R. & P. Steiger. Among firms that manufactured and supplied equipment and components were ACEC, Ateliers de Constructions Electriques de Charleroi, of Belgium (magnet coils and busbars, pole-face windings, six and eight pole lenses, and motor generator set for testing of magnet units); Ateliers de Constructions Mécaniques de Vevey SA, Switzerland (steelwork construction of proton synchrotron halls and lifting apparatus for shielding blocks); Ateliers de Sécheron SA, of Switzerland (transformers); Aluminium Chippis, Switzerland (aluminium for magnet coils and busbars); AMS, Constructions Electriques, France (electrical installations); Ansaldo San Giorgio, Italy (magnet blocks and metadyne sets for lenses); Gerätebau-Anstalt Balzers, Liechenstein (vacuum pumping stations); Brown, Boveri & Co., Germany (main magnet power supply and remote control board for main proton synchrotron substation); Brown, Boveri & Co., Switzerland (Scherbius regulation); CIBA, Switzerland (Araldite and hardening); Curvat, Millet & Co., France (pipes for cooling system); Dullman, Germany (electrical installations); English Electric Valve Co., Ltd., U.K. (valves and accessories for accelerating cavities); Gallay Jean (Usines), Switzerland (vacuum chamber for proton synchrotron, pick-up electrodes tanks, standard racks, sheet metalwork); Gandoni, Vandoni, Italy (civil engineering work); Guffanti, Italy (civil engineering work); Haefely, Switzerland (600 kW Cockcroft-Walton machine); Honeywell Brown, U.S.A. (control system for air conditioning); Ivo Lola Ribar, Yugoslavia (girders for magnet units); Magneti Marelli, Italy (radio frequency accelerating units); Metallschlauchfabrik Luzern, Switzerland (bellows for proton synchrotron vacuum system and special corrugated vacuum chambers); Metropolitan-Vickers Electrical Co., Ltd., [Associated Electrical Industries (Manchester) Ltd.] U.K. (linear accelerator); Mines de Garrot SA, France (barytine for the ring); Monney E, Switzerland (protection blocks); Oerlikon Engineering Co., Switzerland (bending magnets quadrupole lenses and motor generator sets); Philips, the Netherlands (ferrite for radio frequency cavities and electronic equipment); Rade Koncar, Yugoslavia (quadrupole lenses and power supplies); SAMES, France (high voltage generators); Societa Italiana Acciaierie Cornigliano, Italy (steel for the magnet); Siemens Schuckert Werke, Germany (switchgear, power distribution cables and generator sets); Tunzini, France (air conditioning system); Winkler AG, Switzerland (power distribution boards, cable trays); Zimmermann, Germany (magnet cooling system); Zschokke, Spinedi, Losinger (civil engineering work).

# N-Briefs

The South African Cabinet has approved the establishment of a reactor centre for the Atomic Energy Board near Crocodile River bridge.

* * *

The Danish Government has approved an American plan to build a nuclear reactor in North Greenland. It is expected to be in operation this autumn.

* * *

The Morgan Crucible Co., Ltd., Battersea, recently sent about 50 of their managers on computer courses organized by International Computers & Tabulators, Ltd.

* * *

A substantial reduction in the price of uranium for British nuclear power stations built overseas has been made. The new price for each metric ton of uranium contained in fuel elements is now £17,000, instead of £20,000.

* * *

The boiler glandless circulating pumps for the Trawsfynydd nuclear power station are to be supplied by Hayward Tyler & Co., Ltd., a member of Stone-Platt Industries. The contract, placed by International Combustion, Ltd., is worth about £100,000.

* * *

A conference on the use of radioisotopes in the physical sciences and industry is to be held in Copenhagen, September 6th-17th. It is to be arranged by the International Atomic Energy Agency and over 500 scientists from the 70 member states of the Agency are expected to attend.

Australia's first nuclear reactor at Lucas Heights, near Sydney, is now operating at full power. Scientists are placing experimental rigs in the reactor for first irradiation tests, which will subject materials likely to be used in future power reactors to intense radiation many times more than they would have to withstand in a power reactor.

* * *

The Electric Resistance Furnace Co., Ltd., has received an order from the UKAEA for furnaces for the heat treatment of nuclear fuel elements. The order, valued at over £15,000, covers the supply of six Efco-Lindberg furnaces fitted with external forced-convection heating units. The company has already supplied 12 furnaces of the same type for the same process.

* * *

The UKAEA is establishing a Mathematical Physicists Group at Dounreay; this will be engaged on the formulation and, in certain cases the solution of problems in the field of applied mathematics and theoretical physics. The Authority is seeking recruits in this field and has indicated the scope for qualified physicists in managerial and advisory capacities.

* * *

Some 20 radiobiology and research workers have been meeting in Vienna to assist in integrating IAEA radiobiology research programmes in selected fields and in the critical evaluation of research methods. The workers will also make suggestions on the further development of the Agency's programme of research contracts in radiobiology. At present, IAEA has awarded 20 such contracts relating to the biological effects of ionizing radiation at the cellular and the sub-cellular level.

An order for what, when completed, will be one of the largest electronic computer installations in Europe, has been placed with EMI Electronics, Ltd., by the Ministry of Pensions and National Insurance. The computer, an all-transistor EMIDEC 2400, will cost over £500,000 to manufacture and install The computing centre will be set up at the Ministry's Newcastle establishment to deal with the huge volume of data processing connected with the new Graduated Pensions Scheme.

* * *

The Australian Atomic Energy Commission has called for a single set of laws applied by one authority to control the use of radioactive materials in Australia, for the safeguard of public health. The Commission's official organ says a clear authority is required to aid a long-term programme. Lack of suitable legislation in any one State could impair control in others. Research and development leading to nuclear power stations should not be hampered by doubts about the legal issue of safety.

* * *

Berkshire County Council and the Oxford City Council contend that the ultimate staff at the thermonuclear research centre the UKAEA are to establish at the Royal Naval Airfield, Culham, Oxfordshire, should not exceed 1,000. Although the airfield is in Oxfordshire many houses for the staff will be built in Berkshire, hence the County Council's interest. Apart from the question of staff, Berkshire have no serious objections to the centre. Oxford, however, say that it is at variance with their policy in relation to city expansion.

# CONSORT—*New U.K. Research Reactor*

## JOINT DESIGN OF FIRM AND UNIVERSITY

### *Costs about £50,000*

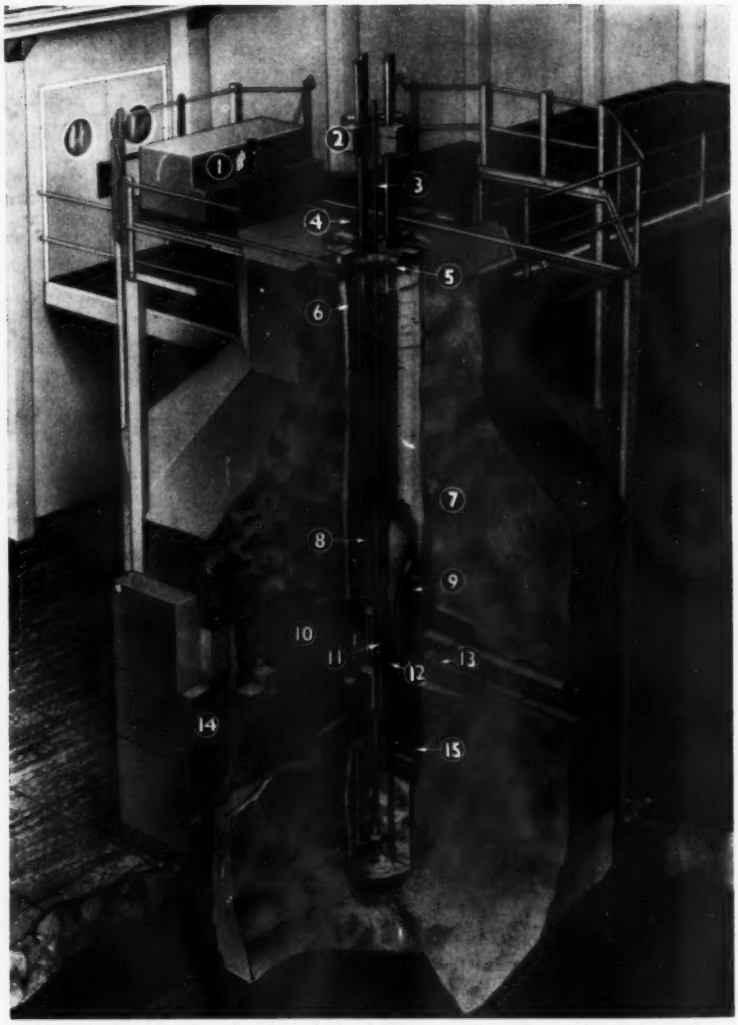
A NEW design of nuclear research reactor is to be marketed by The General Electric Co., Ltd., of England. This reactor, CONSORT, is one of an inherently safe type, using ordinary water as both moderator and coolant. It has been designed jointly by the GEC-Simon-Carves Atomic Energy Group and the nuclear power group at the Imperial College of Science and Technology, London University.

The design was originally produced for the proposed installation to be operated by the nuclear power group of Imperial College, under the leadership of Professor J. M. Kay, at a convenient site outside London. This proposal, which is an integral part of the College's programme for the expansion of its nuclear engineering training and research facilities, has been approved in principle but at present awaits financial sanction before an order can be placed with GEC. The cost of the reactor is approximately £50,000.

### *Best of Two Designs*

The new reactor was designed with a view to combining some of the principal advantages of the two well-known existing types of water-moderated research reactors, the "swimming-pool" type and the "enclosed-tank" type. In the former design, the reactor core is housed in a large tank of water at a substantial depth below the surface so that the water itself provides all the shielding necessary above the core. This arrangement offers the advantages of good accessibility and ease of handling of the fuel elements.

The enclosed-tank reactor uses a comparatively small tank of water with concrete shielding above the core as well as round the sides. The whole assembly is more compact than the swimming-pool type with the result that it is much easier to locate external experimental assemblies close to the core itself. On the other hand, a relatively complex fuel-handling system is required.




**Artist's impression of section through the GEC-Simon-Carves-Imperial College reactor, CONSORT.** Key to numbers:—1 Shielding trolley; 2 Control rod mechanism; 3 Vertical experimental tube; 4 Channel for water connections; 5 Perspex dust cover; 6 Tank; 7 Biological shield; 8 Control rod; 9 Experimental face; 10 Thermal column; 11 Fuel elements; 12 Core support plate; 13 Flux-measuring instruments; 14 Concrete shielding blocks; and 15 Shielding plugs for element storage holes

### *Effective Compromise*

CONSORT provides a most effective compromise between these designs, combining ease of fuel-handling with compactness and good accessibility to the core for experimental facilities. The core is located only 10 ft below the surface of the water moderator in an open-topped tank, but additional shielding is provided in the form of movable concrete-filled trolleys which cover the top of the tank while the reactor is in operation. It has been possible to incorporate an experimental "bare face," protected by portable shielding blocks, closely adjacent to the reactor core, a most important facility for research and training purposes. When the reactor is shut down, the shielding trolleys can be withdrawn and mani-

pulation of the fuel elements can then be carried out beneath the water, under direct observation by the operator using simple manual techniques. Furthermore, the whole design is based on the use of a well-proved type of enriched-uranium-alloy fuel element which is readily obtainable from the United Kingdom Atomic Energy Authority as a standard production item.

### Rating of 10 kW

The new reactor has been designed primarily as a source of neutrons for use in experimental work for research and training purposes. The rating of the Imperial College design for continuous operation is 10 kW and, at this power level, a flux of approximately $3 \times 10^{10}$ thermal neutrons and $2 \times 10^{10}$ fast neutrons/cm²/sec is available at an experimental face in the wall of the reactor tank adjacent to the core. A similar flux can also be obtained at the inner face of a graphite thermal column on the opposite side of the tank.

The bare experimental face is a particularly versatile facility. It allows experimental assemblies to be built very close to the reactor core, thus providing them with a high neutron input. If it is desired to feed a vertical beam of neutrons to an experimental assembly, as may be convenient with water-moderated systems, this can be achieved by means of a dual-purpose thermal column, available as an optional extra. This consists of a horizontal column of graphite built against the bare face and having a vertical stub at its outer end. By means of suitable voids in the graphite the neutron flux at the end of the stub may be optimized for both strength and distribution. The dual-purpose column may at the same time be used to provide a horizontal beam of neutrons if required.

### Radial and Vertical Tubes

Other experimental facilities can be provided in the form of one or more beam tubes issuing radially from the reactor tank at core level while a vertical tube through the centre of the reactor core permits the cycling of specimens into and out of the central flux of $4 \times 10^{11}$ fast and $2 \times 10^{11}$ thermal neutrons/cm²/sec.

The core of the reactor is built up from between 20 and 24 fuel elements of the standard MTR type in which the enriched uranium-aluminium-alloy fuel is fabricated in the form of slightly curved plates clad in aluminium. A number of these plates are assembled to form an approximately square-sectioned element such that the coolant can flow between the faces of adjacent plates.

Below the level of the cylindrical core within the reactor tank, shielded fuel-element storage holes are provided, each fitted with a removable stainless-steel shielding plug. These compartments can accommodate a full charge of 24 fuel elements. The design of the storage area is such that there is no possibility of inadvertently assembling a critical mass of fuel.

### The Water Tank

The core, with its support structure, is mounted near the bottom of a vertical cylindrical tank filled with water to act as moderator, coolant and shield. The tank, which is made of high-purity aluminium, $\frac{3}{8}$ in. thick, is open at the top, but a Perspex cover keeps the water surface free of dust. Provision is made for the dispersal of hydrogen evolved in the moderator during operation of the reactor and also for the detection and collection of fission products in the event of a fuel-element failure.

The tank is surrounded by a concrete biological shield, octagonal in plan, with a thickness of approximately 7 ft 6 in. reducing to 3 ft near the top of the tank. The main body of this shield is a monolithic structure, but on two diametrically opposite faces, removable concrete blocks are employed so as to permit the necessary flexibility in the disposition of shielding around experimental assemblies set up adjacent to the experimental face and the thermal column.

Axial shielding above the core consists of a 10 ft depth of water which is supplemented, while the reactor is in operation, by a 2 ft 6 in. thickness of concrete. This concrete shielding takes the form of two movable trolleys which run on guides set in the top face of the reactor structure, the joint between the trolleys being stepped and shaped to fit around the control rod support tubes. The trolleys are moved by hand, and interlock limit switches are fitted both at the fully open and at the closed position.

The reactor is controlled by means of vertical neutron-absorbing rods which are of flat section and pass through guide tubes between adjacent fuel elements. There are two shut-down rods, one fine control rod and one safety rod. All these rods are raised and lowered in their guides by means of driving mechanisms mounted above the reactor.

### Alternative Control Rods

Two alternative types of control-rod mechanisms are available for this reactor. In one design, the control rods are operated magnetically and in the other by winch.

The instruments required for the measurement of flux and other control functions are mounted in shielded holes close to the wall of the reactor tank, the necessary connections being carried in tubes passing through the biological shield. The control equipment and instrumentation needed for operation of the reactor are housed in panels in a separate control room.

The fuel-handling arrangements are such that, once the reactor has been shut down and the shielding trolleys withdrawn, fuel elements can be transferred between the core and the storage holes in complete safety by means of a simple manual operation. The handling tool consists of a long tube with a grab-head at its lower end and release levers at the top. The jaws of the grab are shaped so that an element cannot be released until its weight is fully supported either in one of the storage holes or by the core-support plate. Furthermore, the tool is designed to limit the height to which an element can be raised above the core, thus ensuring that the operator is always shielded from radiation by an adequate depth of water.

### Water System

The water connections to the reactor, comprising inlet, outlet and overflow pipes, enter the tank through the top. On leaving the reactor, the water is pumped through an external circuit by means of a motor-driven pump capable of handling 400 gal/hr. The main circuit includes filters for the removal of any entrained solid particles, and a cooler which is controlled to ensure that the water-temperature at inlet to the reactor core is kept at a steady value.

# INSTITUTION OF NUCLEAR ENGINEERS

## COUNCIL MEETING MARCH 11th, 1960

•

B.N.E.C. More Friendly?

Plans for Teaching Aids Guide Discussed

Over 600 Members

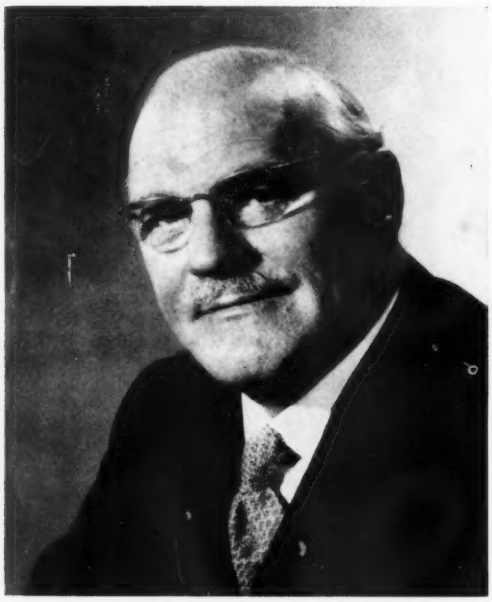
POSSIBLE support of the Institution of Nuclear Engineers from leading members of old-established professional institutions was hinted at by Sir John M. Duncanson, president, at the March Council meeting. He said certain persons had approached him about the Institution and had made suggestions about the appointment of honorary vice-presidents. With the Council's permission, Sir John said he would like to pursue the matter on their behalf in informal discussion. The Council gave their approval.

The outcome of such discussions could well mean a change of attitude towards the Institution by the British Nuclear Energy Conference, which, as Sir John pointed out, had " not been very kind " when the Institution was formed. In Sir John's opinion the two organizations had entirely different functions.

### *Eminent Men Sought*

The appointment of honorary vice-presidents was very much in the minds of Council members at this meeting and a considerable amount of time was spent in discussing the names of prominent scientists, engineers and businessmen who could be approached with a view of asking them to honour the Institution by accepting a vice-presidency.

Coupled with the task of finding honorary office holders was that of securing the services of an eminent person to give an inaugural address. Sir John announced that he had approached a well-known physicist to replace the late Professor Skinner who was to have given such an address and he expressed confidence in receiving a favourable response.



*Sir John M. Duncanson, President*

Dr. F. R. Paulsen put forward an idea which he thought might be useful. It was that the Institution should prepare a handbook on aids used for teaching nuclear subjects. He said that there was a great need to get nuclear ideas over to the young student, particularly at grammar school and technical college level. One of the difficulties in achieving this was the high cost of currently available equipment. There were, however, teachers who partly overcome this problem by using specially designed but simple apparatus. Often they made it themselves.

If all the ideas for such equipment could be collected together and then made available to all teachers, the Institution, in Dr. Paulsen's estimation, would be making a valuable contribution to the furtherance of its aims. He cited as a precedent for this type of publication the UNESCO " Source Book for Science Teaching " which covers aids used in general science.

Dr. Paulsen's suggestion met with general approval, though doubts were expressed about it being possible to produce a book. The bugbear was economics. It was suggested that this difficulty might be overcome by publishing the information collected in the Institution's journal, NUCLEAR ENERGY. As a start to the project the secretary was given authority to seek the co-operation of the members of the journal's panel of international editors. These were mostly connected with educational establishments and represented countries throughout the world.

### *Text Book Idea Rejected*

Other suggestions for work that could be undertaken by the Institution had a far less warm reception. There was, for instance, the idea written in by a member that the Institution should publish a digest of recommended text books. The Council were of the opinion that it was unwise to embark on a project which would involve them in giving collective approval or disapproval to something which is often regarded

as being a matter of personal opinion. They felt a better service was provided by members writing individual reviews. It was suggested that when the Institution had established its own examinations they might then put forward a list of recommended text books for the students to study.

### Too Early for Service

The idea of a Research Information Service also received scant support, it being felt that this was too large an undertaking for the Institution at present. The purpose of such a service would be to provide members with regular synopses of latest research and development work.

The publicity critics were answered by the secretary who said that an endeavour was to be made to give better coverage to the meetings. Sir John thought a detailed list of members would fill a much felt gap and Mr. Pinkerton announced that it was planned to publish a year book in December which listed members, and contained the articles of association of the Institution and an account of the first annual dinner.

This function was then discussed by the Council it being decided that the Savoy would make an amenable venue and a date in late October or early November would be suitable. The secretary was asked to fix a definite date.

It was announced that since the previous meeting the Finance and General Purposes Committee had approved of 66 new applications for membership bringing the total number of members to date to 629.

On the question of subscriptions it was agreed that members joining after June of any year would have to pay only a half year subscription and those who joined in December would automatically be accounted for from the following January.

Income tax raised its ugly head. Many members have written to ask whether they could claim a tax rebate in respect of their subscriptions—Mr. Coombs, chairman of the Finance and General Purposes Committee, said he felt that such a body as the Institution would qualify members for some sort of concession. The question was being investigated by the Institution's solicitor and he hoped to be able to present a report to the Council at its next meeting.

### Transatlantic Interest

Sir John said he was very keen in encouraging American and Canadian interest in the Institution and he named a couple of prominent Canadians who had in fact shown interest.

No doubt it was in the minds of the Council that Dr. Grassam, who had that very day left for a tour of American universities, would spread the word of the Institution round the States. At the same time they would look forward to his return and hearing of his experiences and impressions.

**(*Left*) Applications for membership to the Institution being scrutinized by members of the Finance and General Purposes Committee. Elected members of this committee are (*above, left to right*) Mr. D. S. Watt, vice-president, Mr. F. L. Coombs, committee chairman, and Mr. T. P. Everett, treasurer and junior vice-president**

## NEW MEMBERS

J. O. Atherton, Southminster, Essex. M
A. Barton, Southminster, Essex. A
T. A. Bevan, Berkeley, Gloucester. A
E. LaV. Bilton, Greenford, Middx. A
A. R. Buchanan, Latchingdon, Essex. M
A. S. Butcher, Southminster, Essex. M
N. F. Cannon, Heath, Cardiff. M
G. A. Child, Smethwick, Staffs. A
T. W. Cooper, Stoke-on-Trent. A
P. R. Digwood, Southminster, Essex. A
A. T. Fletcher, Southminster, Essex. A
R. F. Fordham, Harwell, Berks. A
B. E. G. Garner, Abingdon, Berks. A
J. G. Gommas, London. M
W. Haley, Salisbury, S. Rhodesia. A
D. B. Halliday, Chilton, Didcot. M
A. G. Harvey, Southminster, Essex. A
P. A. Hutchins, Whitehaven, Cumberland. A
B. H. Jones, Abingdon, Berks. M
A. G. B. Kerr, Epsom, Surrey. M
A. Knight, Northampton. A
J. M. Margetts, Orpington, Kent. A
M. R. Marshall, Feltham, Middx. A
M. A. McTaggart, Ruislip, Middx. M
K. J. McKeown, Victoria, London. A
F. E. Mundy, Latchingdon, Essex. A
R. A. Oakley, Southminster, Essex. A
W. K. Philp, Southminster, Essex. M
E. Poole, Dartford, Kent. A
A. J. Powell, Southminster, Essex. A
H. Porter, Motherwell, Lanarkshire. M
D. Price, Southminster, Essex. A
K. H. R. Rose, Southgate, London. M
E. R. Roxburgh, Walworth, London. M
L. V. Tickner, Southminster, Essex. A
N. R. Treliving, Bishopston, Bristol. A
W. G. Turner, Burnley, Lancs. A
G. W. Wearne, Southminster. Essex. A
J. G. Webb, Horfield, Bristol. A
N. E. Williams, Manchester. A
J. F. R. Williams, Didcot, Berks. M
B. Yates, Leigh, Lancashire. A

# Experimental Studies of NATURAL CIRCULATION BOILING*

## THEIR APPLICATION TO REACTOR PERFORMANCE

by

P. A. Lottes, J. F. Marchaterre, R. Viskanta, J. A. Thie, M. Petrick,

R. J. Weatherhead, B. M. Hoglund, W. S. Flinn

(*Continued from page 121*)

THE procedure for calculating the natural circulation performance of a reactor core is complicated due to the additional complicating factors of constant inlet subcooling across the core and the power distribution within the core. The general procedure for such a calculation is basically the same as outlined previously. Various channels are selected at points along the core radius and are analysed for an initial assumed inlet subcooling (which must be used in equation (xiv)). The performance of the individual channels are adjusted until there is agreement with the known power distribution. The total core recirculation flow rate is then computed from the radial velocity distribution and a heat balance is made to circulate the subcooling. If the calculated subcooling is not in agreement with the assumed value, the calculation procedure is repeated until agreement is reached.

### BORAX Experience

*Boiling Reactor Experiment (BORAX) calculations:* Using the method of analysis previously described, the exit steam volume fraction in the hot channels was computed for three boiling reactors with clearly defined instabilities. Estimations of steam volume fractions at low pressures are difficult due to the inability to predict slip ratios accurately. Even though the accuracy of the calculated steam volume fractions is questionable, significant comparisons can be made from Table II.

Table II.—Small Oscillation Thresholds*

| Reactor | Pressure in lb/sq.in. gauge | Per cent reactivity in voids | kW/litre of core | Estimated $\alpha_{ex}$ in hot channels |
|---|---|---|---|---|
| BORAX I .. | 0 | 1.4 | 6.14 | 90 |
| BORAX II .. | 150 | 1.2±.4 | 7.9±2.6 | 50 |
| BORAX II .. | 300 | 3.2 | 21 | 48 |
| BORAX IV .. | 0 | 0.4 | 8.41 | 80 |
| BORAX IV .. | 70 | — | 21 | 80 per cent. |

*The threshold of instability was defined in the presence of noise by requiring two or more self-induced cycles (of the same period) in succession without noticeable phase shifting.

This lists the reactors and the estimated exit steam volume fraction at the onset of instability.

BORAX II showed instability at an estimated exit volume fraction of 50 per cent. for two different pressures, even though the reactivity in voids varied by a factor of 3. BORAX IV showed similar dependency on voids but at a different void level. BORAX II has a 2 ft core with a 2 ft riser. BORAX IV had a 4 ft core with a 4 ft riser. It is reasonable to assume that the threshhold of hydrodynamic instability would be different for the two systems. This is indicative that the mechanism of instability may be the same as that observed in the non-nuclear tests.

*Parametric studies of boiling reactors:* Sufficient experimental data has been accumulated so that an analytical parametric study could be undertaken to assess the capabilities and potential of the natural circulation boiling type reactor. A wide range of possible design parameters such as system pressure, power density, average core coolant density, flow channel hydraulic diameter, core height, riser height, recirculation flow rate, exit steam volume fraction, etc., were investigated and their effect in reactor performance was determined. The calculation methods and analytical procedures used were discussed previously. The analyses were based on engineering and correlation extrapolations obtained from lower pressure boiling studies.

### Base for Estimates

The results of the study[8] were compiled into a series of graphs which show the inter-relationship between the various parameters and from which a quick estimate of reactor performance can be made for many design conditions. Typical results obtained are shown in Figs. 20-23. The graphs represent the best estimate of natural circulation boiling water reactor performance that can be made at present utilizing information currently available. No study has been made of the possibility of burnout or instability; therefore,

**Paper presented at 2nd International Conference on Peaceful Uses of Atomic Energy, Geneva, 1958.*

some of the operating conditions shown in the figures may be unattainable.

The results of the study indicate that the potential of natural circulation reactors appears very good and less limited than has generally been believed. Since boiling reactor design is quite complex and since a number of factors that contribute toward optimum design require more thorough investigation, the true capabilities of boiling reactors are not completely known at present. However, some specific conclusions that can be drawn from this study are:

(1) Forced circulation is not always necessary to achieve high flow rates. Natural circulation velocities can be greater than flow rates normally associated with forced circulation design.

(2) High pressure offers promise of high power density operation.

(3) Power density is likely to be the primary limiting feature of low pressure design, while burnout heat flux is likely to be the primary limiting consideration of higher pressure design.

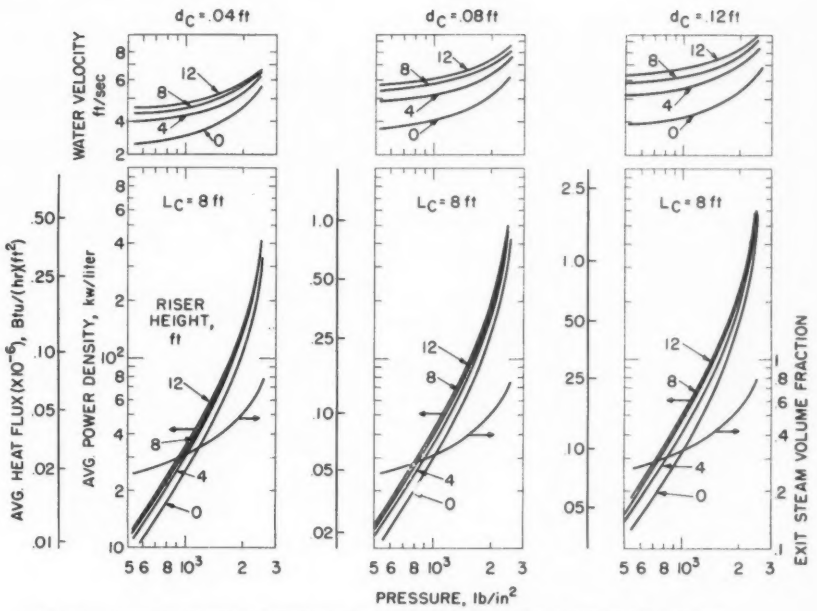



Fig. 21.—Effect of hydraulic diameter on natural circulation boiling reactor performance with a riser ($D_R = D_C$)

*Heat transfer:* Development in nuclear reactors, where exceedingly high heat quantities are generated in comparatively small volumes, focused attention on nucleate boiling as a mode of transferring heat at high rates at almost constant temperature of heat transfer surface. From an engineering point of view the following is to be considered: in the usual convection problem a correlation between heat transfer and temperature is all that is required.

The theoretical equations of Forster and Zuber[9] and Rohsenow[10] for the case of pool boiling and the empirical equation of Jens and Lottes[11] for liquids flowing in tubes in the nucleate boiling region for water at a pressure of 600 lb/sq.in. abs., are plotted in Fig. 24. The curves relating heat transfer to $\triangle T$ are very steep. For a given heat flux the $\triangle T$ given by the three equations, even though they represent two different systems and two different mechanisms of boiling heat transfer, differ only by a few degrees. In the case of boiling heat transfer, as it was already pointed out, the wall temperature will always remain close to the boiling point of the fluid. For design purposes in a constant heat input system it is often unnecessary to predict the wall temperature any closer than this. Calculations of temperature in a reactor design if the heat flux is known do not present many problems, because irrespective of which equation one uses to calculate the surface temperature, the error in surface temperature will be small.

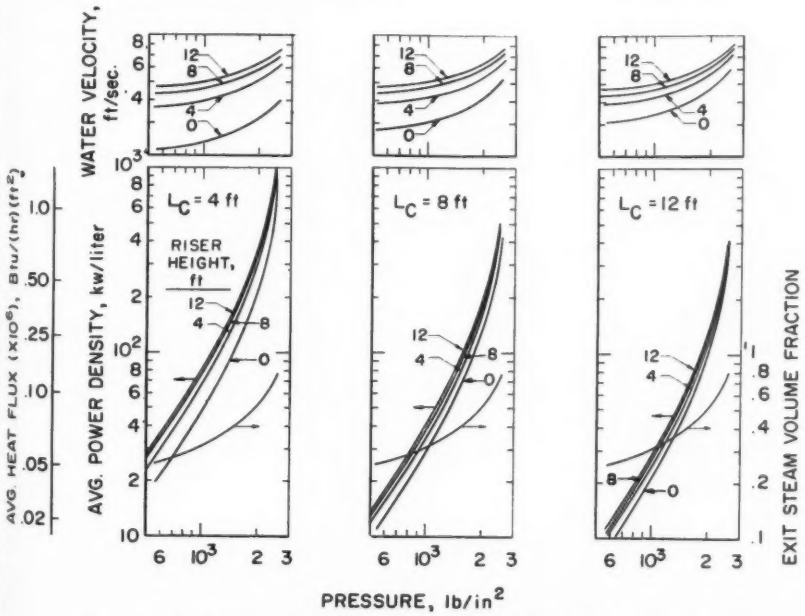



Fig. 20.—Effect of pressure and height on natural circulation boiling reactor performance with a riser ($D_R = D_C$)

*Burnout (critical heat flux):* A major uncertainty in boiling reactor design is the prediction of burnout. It appears that the burnout heat flux is a function of the mass velocity, mixture quality, system pressure, and possibly such additional factors as surface condition, geometry, etc. No correlations of net boiling burnout are known that adequately describe its relationships with these various

parameters. Known data in the literature indicates a peaking of the burnout flux at approximately 1,000 lb/sq.in. and a general lowering of permissible heat fluxes above pressure of 1,000 lb/sq.in. Since there are promising aspects of natural circulation performance at higher pressures, the question of burnout heat flux becomes particularly important. At the higher pressures the boiling length inherently becomes shorter; therefore lower steam volume fraction and qualities will exist in the zone of higher heat flux. This shorter boiling length and its location near the discharge end should be beneficial from the standpoint of both burnout and stability.

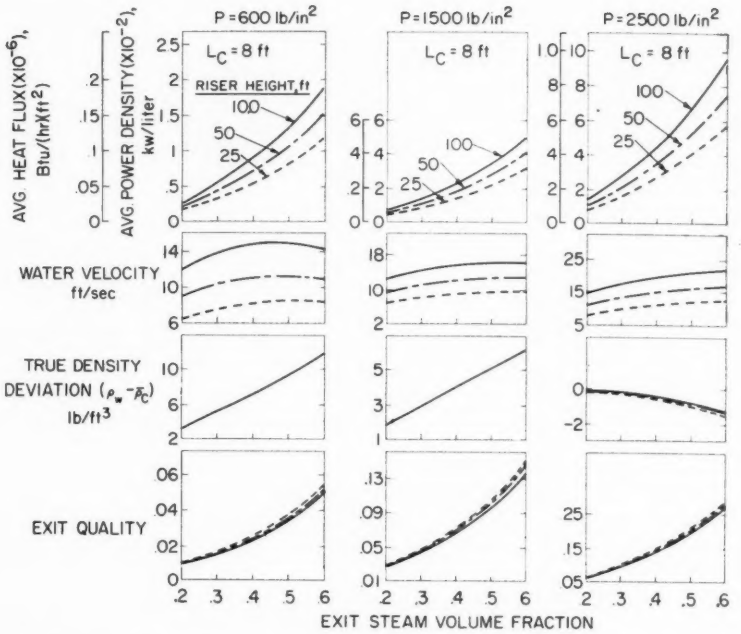



**Fig. 23.—Effect of pressure on natural circulation boiling reactor performance with a riser ($D_R = 1$ ft)**

## Not Enough Evidence

Very high pressure burnout bears further study. The properties of steam and water at pressures slightly less than the critical pressure are such that a sudden phase change in this region may not lead to a burnout or excessive temperature condition due to channel blockage, a condition that can happen at lower pressures.

*Stability:* It is recognized that the instabilities in a water-moderated reactor are much more complex than in the natural circulation boiling loops since they involve feedback functions between steam volume fraction and heat generation. It is believed that the natural circulation boiling reactor stability problem is strongly related to hydrodynamic instability. The mechanism postulated is that flow and steam volume fraction oscillations are the first to occur and are the cause of the resulting power oscillations.

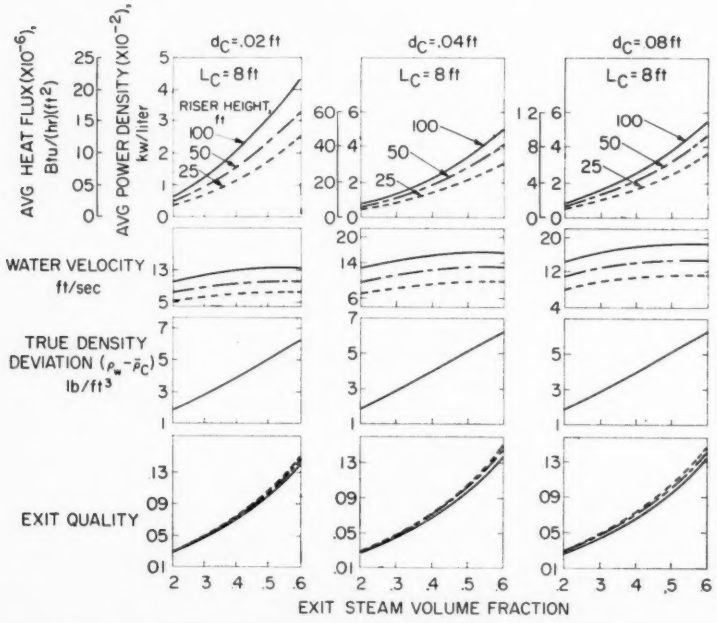



**Fig. 22.—Effect of hydraulic diameter on natural circulation boiling reactor performance with a riser ($D_R = 1$ ft)**

A trend of increased stability with pressure has been shown by natural circulation boiling loop experiments as well as the reactors. Laboratory tests have also shown that increasing inlet resistance always increases stability and offers a practical means of aiding stability. Reactor stability should improve with pressure because of the increased energy of a unit volume of steam and shorter boiling length. It is expected that higher recirculation flow rates, along with lower steam volume fraction will aid stability.

Since heat-input is displaced toward the inlet of the core in the boiling water reactors, the stability becomes more difficult to ensure. From Fig. 15 one can see that the amplitude of steam volume fraction fluctuations is the greatest in the region where the neutron flux is close to maximum.

Only a small variation in the system water level was investigated in the natural circulation boiling loop to determine the influence of water level above the riser on stability. The results are not conclusive. Therefore the effect of water height above core, with or without risers, on stability requires further study.

*Geometry:* The proper selection of a riser is probably the most important single hydrodynamic aspect of

natural circulation boiling reactor design. The effect of risers on reactor performance can be evaluated by determining their influence on coolant flow rate. As the flow rate increases, the ratio of reactor power to steam volume fraction increases, thus improving reactor performance.

## Size a Compromise

With a riser of small hydraulic diameter, the greatest benefit is obtained from the first few feet of riser height since the ratio of percentage additional driving head to percentage addition flow resistance is inherently low. By enlarging the riser diameter the ratio of percentage additional driving head to resistance can be considerably increased.

The selection of the proper core flow channel size is difficult because of the intimate inter-relationship between system hydrodynamics, thermal aspects (burnout), and nuclear kinetics. Small channel spacings result in lower recirculation rates but tend to reduce the heat flux and increase the fuel to moderator ratio. Larger channel spacings produce the opposite effect. The actual channel size must therefore be a compromise between the competing factors since each factor in itself may impose limiting restrictions.

*Pressure:* High pressures offer promise of high power density operation. For a given exit steam volume fraction, power density increases markedly with pressure and circulation rates do not decrease. The natural circulation rates do not drop off with pressure primarily because of the decrease in friction. Also, at very high pressure there is additional hydrodynamic driving head due to the density-temperature relationship of water. At high power density operation this additional head can be of great significance if the cold make-up water is injected at the top of the downcomer. The inter-relationships of power density, coolant density and inlet subcooling at high pressures indicates that the core coolant density could remain fairly constant as power is varied, as shown in Fig. 23.

The possible beneficial aspects of high pressure operation have to be weighed against associated drawbacks. As mentioned previously, burnout consideration presently appears to dictate a general lowering of permissible heat fluxes above system pressures of 1,000 lb/sq.in. Maximum reactor vessel diameter at high pressures further lowers the attainable total power output.

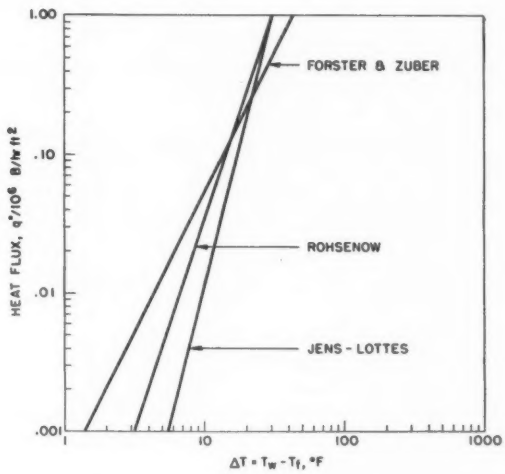



**Fig. 24.—Comparison of boiling heat transfer correlations**

*Nuclear considerations:* Design criteria on boiling reactors arise out of fields of both reactor statics and reactor kinetics. For the former in common with most other reactors, the amounts of fuel and fertile material must be computed to obtain the desired reactivity and conversion ratio. The flux distribution, however, has special considerations in boiling reactors because the steam voids influence the local material buckling and hence the flux shape. The latter determines the power distribution and hence the local voids. Methods of solving this combination hydrodynamic and neutron physics problem have been developed[12].

## Void Coefficient

Theoretical studies of boiling reactor stability[12] have shown that certain core time constants, such as transit times for fuel heat flow and coolant channel steam flow, play a role in stable reactor design. Also an important quantity both in stability as well as safety considerations is the void coefficient, *i.e.*, the amount of reactivity per unit of steam void. For safety a large negative coefficient is desirable, while for stability the permissible range of values depends on the system's feedback processes, magnitudes and time constants.

Typical void coefficients of these reactors have been in the range of $-.05$ to $-.4$ per cent. reactivity/per cent. void. For a given moderator and fuel this number is largely determined by the volume fractions of these as well as the reactor size. Generally speaking, small reactors with low moderator content have large negative void coefficients.

*Other considerations:* It should be mentioned at least for the sake of completeness that fields of mechanical, metallurgical and chemical engineering as well as reactor economics enter into core design. Presumably these would have selected the natural circulation boiling concept in the first place, and continue to play a role in core design with factors such as costs, availability, material compatibility and suitability of materials; core life, processing and fuel recycling; and finally economic and other type goals of the reactor.

*(Conclusion)*

### References

[8]FLINN, W. S., and PETRICK, M., "Performance and Potential of Natural Circulation Boiling Reactors." ANL-5720, 1957.

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[10]ROHSENOW, W. M., "A Method of Correlating Heat Transfer Data for Surface Boiling of Liquids." *Trans. Am. Soc. Mech. Engrs.*, 74:969, 1952.

[11]JENS, W. H., and LOTTES, P. A., "Analysis of Heat Transfer, Burnout, Pressure Drop and Density Data for High Pressure Water." ANL-4627, 1951.

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*(A list of further references referred to in the compilation of this article is published on page 180)*

**Nuclear engineering presents lubrication problems which are not encountered in any other industry. The intelligent use of molybdenum disulphide has, however, provided an answer to a considerable number of difficulties which have so far arisen**

# Lubricants for Nuclear Engineering

by Peter Jost, MIMechE, MemASME, MIProdE,*
and W. Bye, BSc

THE ever increasing use of nuclear energy has presented the lubrication engineer with some unique problems. These problems fall into two main categories. The first category is concerned with the deleterious effects of radiation on conventional lubricants. The second arises from the necessity for excluding maintenance men from large areas on the grounds of safety, so that any system of lubrication in these areas must function perfectly for long periods without supervision. These twin requirements of severe working conditions coupled with the need for trouble-free operation are mutually contradictory and it was clear from the start that they called for a new approach to the whole idea of lubrication in the nuclear energy field.

Fortunately, the demand by other industries for a method of lubrication which would prove reliable even under the most adverse conditions had already resulted in an entirely new and effective approach, based on the use of molybdenum disulphide or $MoS_2$. This material has a laminar structure comprising a layer of molybdenum atoms sandwiched between two layers of sulphur atoms. Although the bond between adjacent layers of sulphur atoms is very weak, the sulphur atoms are strongly attracted to the molybdenum layer of the sandwich or to any other metallic atoms with which they come into contact (*see* Fig. 1). This means that a layer of molybdenum disulphide will readily build up on any metal surface on which the material is deposited. Should a second surface then pass across the already coated surface, friction will be minimized by virtue of the low shearing force across the weak sulphur-sulphur bond.

The outstanding lubrication action of $MoS_2$ cannot, however, be explained purely in terms of the weakness of the sulphur-sulphur bond. The present trend of thought is that the high local temperatures resulting from the rubbing action of minute asperities on the mating surfaces initiate a chemical reaction between the $MoS_2$ and the metal surface, propably under the catalytic action of the molybdenum. The result is that any further direct metal-to-metal contact between the mating parts is inhibited.

Instead of peaks now welding to the opposite surface and being torn away with a stick-slip action, the metal is deformed plastically to fill the hollows below. By virtue of this true "running in" (rather than "wearing in") process, the real bearing area of both mating surfaces is strikingly increased.

In many cases, the reduction in true surface pressure resulting from this increase in bearing area will enable normal lubricants to cope satisfactorily with the reduced loading. In the atomic energy field, however, the paramount interest in safety demands the continuing application of molybdenum disulphide.

A typical example of the type of "nuclear" application in which $MoS_2$ has proved uniquely suited is seen in Fig. 2. This illustration shows the main bevel gears used in the 132 control rod actuators for the two nuclear reactors at Berkeley. These gears and bearings are located inside the pressure vessel where the use of orthodox liquid or semi-liquid lubricants is not permissible. Instead a dry-bonded film of $MoS_2$, based on Moly-VI-Bond, is substituted.

After a phosphate pre-treatment, the $MoS_2$ coating is applied by brush or spray after a suitable resin binder has been incorporated. This is cured by baking to retain the solid coating securely in position until the process of running-in has built up a film of $MoS_2$ as an integral part of the metal surface in the manner described

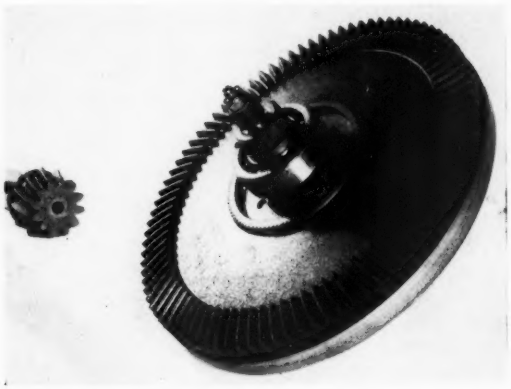


**Fig. 2—A dry-bonded film of $MoS_2$ lubricates these gears and bearings used in the Berkeley reactor control rod actuators**

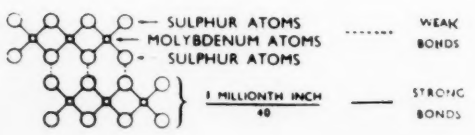



**Fig. 1—Diagram illustrating the laminar structure of $MoS_2$**

*Managing director, K. S. Paul (Molybdenum Disulphide) Ltd., London.

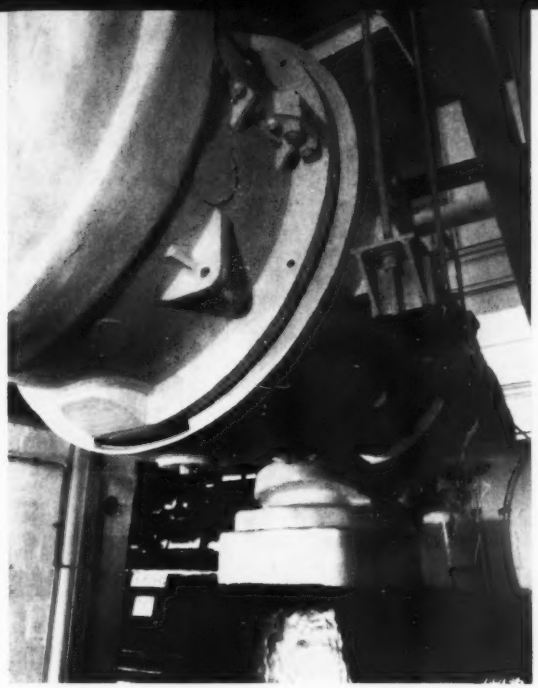


**Fig. 3.—$MoS_2$ in the form of Moly-Paul General-Purpose Paste 100 is used on the bellows hinge pins in the carbon-dioxide duct circuits at Calder Hall and Chapelcross**

above. Test results indicate that this method of dry lubrication greatly reduces wear and yields a satisfactory gear life under operating conditions.

In one way, the absence of an oxidizing atmosphere in a nuclear reactor is well suited to bring out the best performance of $MoS_2$. Thus, the normal temperature range of $MoS_2$ is from −300°F. to +800°F. (say 150-435°C.). In vacuum or inert gases, the upper limit is, however, extended to 2,100°F. (about 1,150°C.) Although having few practical applications at the present time, even when running red hot, the coefficient of friction of a $MoS_2$ film created *in situ* is only around 0.07.

Another interesting application of $MoS_2$ is on the bellows hinge pins of the duct circuits for carbon dioxide at Calder Hall and also at Chapelcross (*see* Fig. 3). These hinge pins are designed to provide compensation for varying temperatures and are thus subject to intermittent motion. When conventional lubricants are used under such conditions, they tend to get squeezed out while the mechanism is at rest, until metal-to-metal contact eventually occurs. Considerable forces are then necessary to initiate movement and undue wear inevitably occurs. The $MoS_2$ film is, however, an integral part of the metal surfaces and is moreover naturally self-healing, so that ideal lubrication is ensured even after prolonged idleness.

## For Conventional Plant

A similar situation arises in the generating section of nuclear power stations. Here the main shaft bearing pedestals of the steam turbines are provided with sliding surfaces to allow for thermal expansion as the temperature rises to the extremely high values now used. At an operating temperature not far short of 1,000°F., for instance, conventional lubricants are completely useless and, indeed, tend to "glue" the mating surfaces together rather than keep them apart. Under oxidizing conditions, even a film of $MoS_2$ will tend to give a less effective lubricating effect at such temperatures. Since the design effectively excludes the atmosphere, however, efficient operation can be obtained at temperatures in excess of 900°F. (482°C.) by initially coating the mating surfaces with a dry $MoS_2$ film and providing "follow-up" lubrication with high-concentration of $MoS_2$ in a carrier of polyethylene glycol (Polypaste 300).

## Suitable at High Temperatures

When air is completely excluded by the design, similar high-concentrate $MoS_2$ paste of this type can provide satisfactory lubrication at temperatures as high as 1,700°F. (say 925°C.). Figure 4 shows cylinder joint bolts which have been subjected to temperatures around 900°F. for periods up to four years and have then been removed without trouble to allow the turbine to be overhauled.

Space has allowed the choice of only a few examples of the use of molybdenum disulphide in the atomic energy field. Enough has, however, been said to show that this uninteresting looking grey powder—with a specific weight of 4.9—is capable of solving satisfactorily problems which can be handled by no other lubricant. In support of this are recent American reports which show that during press-fit tests using irradiated and non-irradiated $MoS_2$ as the lubricant, the coefficient of friction was 0.056 in the case of unexposed $MoS_2$ and 0.057 in the case of the exposed $MoS_2$.

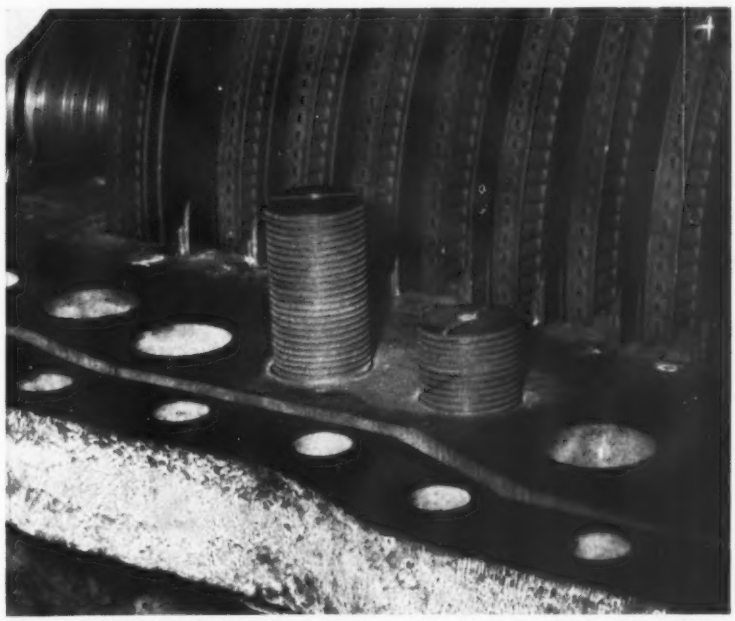
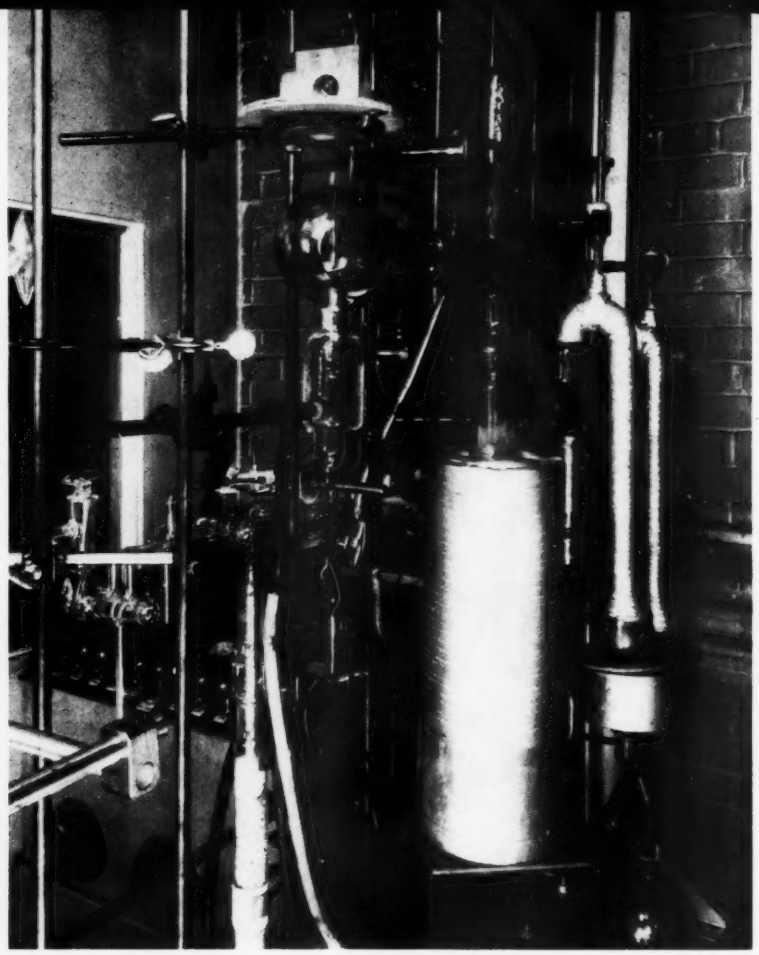
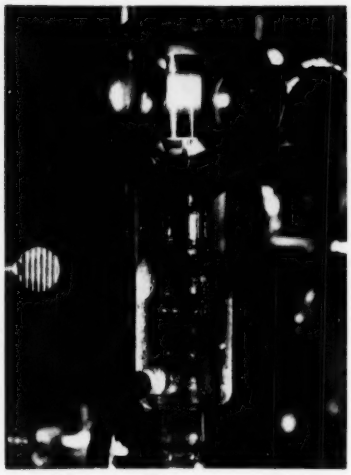


**Fig. 4—Cylinder joint bolts such as these are still readily removed from their turbine casing after being subjected to temperatures around 900°F. for periods up to four years** (*Photograph by the Central Electricity Board*)

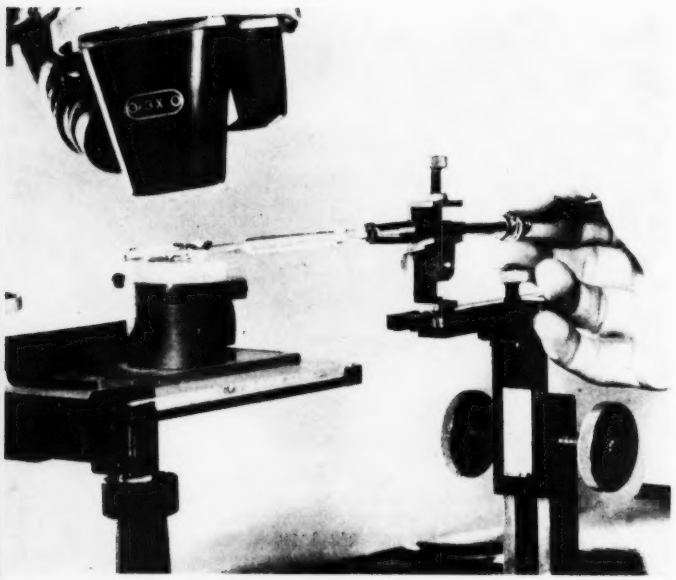
**Shown on the right is the apparatus used by members of the Chemistry Division of the Argonne National Laboratory to prepare microquantities of rare metals. The glass bulb in the centre (*shown in close-up below*) holds a tiny electric furnace into which compounds are introduced and converted into metal by reduction. To the right of the furnace bulb is the equipment for removing air from the bulb. The lower picture shows a microcone (*directly under the microscope at left*) being loaded with a chemical solution by means of a micropipette held by means of micromanipulators (*right*). Solutions less than 0.1 m.litres in volume are handled with this apparatus**





# Ultramicrotechniques

## Special Apparatus to Overcome Processing Problems



ONE of the major problems in the early stages of the development of nuclear energy was the design of a satisfactory chemical process for the separation of plutonium from uranium and from the numerous highly radioactive by-products formed in the fission process. The problem was complicated by the fact that only microgram quantities of plutonium, which had been laboriously produced by bombardment of uranium with neutrons from cyclotrons, were available for experimentation at the time.

However, by the application of " ultramicrotechniques " at the Argonne National Laboratory in the United States, it was possible to test proposed separation processes at the concentrations of plutonium expected in the yet to be constructed plant. These studies were carried out using weights of plutonium and reagents in the range of 0.1 to 100 microgrammes (1/10,000 to 1/100,000 of a gramme) and volumes of solution of 1/100,000 to 1/10 of a millilitre. The value of these microchemical experiments was effectively demonstrated by the initial and continued success of the process when it was put into plant operation.

The " ultramicrotechnique " also was used to prepare, identify and determine the chemical and physical properties of plutonium metal and many plutonium compounds on the microgramme scale before larger amounts of the element became available from pile production. In addition to plutonium, the other transuranium elements, neptunium, americium and curium, as well as other scarce radioactive elements such as technetium and actinium, have been successfully studied by these methods.

# Radiation in the CHEMICAL INDUSTRY

by F. R. PAULSEN, BSc, PhD, FRIC, MINucE

RESEARCH into the effects of radiations on living organisms has clearly indicated the amazing complexity and diversity of chemical reactions which can be induced by atomic particles and emissions. It is hardly surprising, then, that much thought has been given to the possibilities of bringing such nuclear forces to bear in the manufacture of various commodities for the use of mankind. The objective is either to make present chemicals by new and cheaper methods, or with greater purity, or to prepare chemicals which could not be made by other means.

For the induction of chemical reactions radiations are to be looked upon as a means of supplying energy, and in this way competing with thermal sources of more conventional types. As possible energy sources there have to be considered fission products, accelerated charged particles, such as electrons, and the photons of *X* and gamma radiations.

Already there are on the market various types of betatron, or machines producing high-energy electrons, designed specifically for the production of chemical changes. These have been used for the sterilization of foodstuffs, drugs, and medical commodities, and also for the modification of polymerized materials, of which more will be mentioned later. The use of such accelerators is very strictly limited, however, and is not extended to the actual manufacture of chemical compounds.

## Most Too Dear

Fission products are becoming more and more plentiful each day, as nuclear power is developing throughout the world. However, most of the energy of fission particles has already been liberated in the reactors which produced them, and in general, they are much too costly for general industrial use. Semi-refined fission products would have an energy of radiation equivalent to 5,000 curies/lb, and activities of the order of millions of curies are required, so that fission products are likely to prove costly. On the other hand, they do show certain advantages in the ways in which they can be handled, so that their use must not be dismissed.

Most conventional methods for the initiation of chemical reactions are effective only within limited temperature ranges, and the types of products formed may vary with temperature conditions. Gamma and *X* photons use most of their energy in ejecting electrons from atoms and molecules, *i.e.*, in ionization.

## Vital Role of Ions

The number of atoms directly attacked by such photons is very small compared with the number attacked by the energized electrons produced by the ionization. The charged or ionized particles penetrate matter and produce ions en route, and also excited molecules. Thus, an atom $A$ may be ionized to give an ion and an electron, *i.e.*, $A=A^{+}=e$; an atom $A$ may also become excited by energy from the moving electron, *i.e.*, $A=A^{*}$ and finally, there may be recombination of the ion and an electron to produce an excited atom, *i.e.*, $A^{+}+e=A^{*}$. It is the ions and excited atoms which are responsible for the chemical reactions.

Yields from chemical reactions induced by radiations are expressed by their $G$ values, which are the number of molecules of product formed as a result of the absorption of 100ev of energy. The higher the $G$ value, the more responsive is the system to the radiation, and the higher is the efficiency of the radiation in promoting reaction. The $G$ values range, in general, from about 0.01 to 10, but many reactions have $G$ values of 10,000 or more.

Obviously, the cost of a radiation-induced reaction for which the $G$ value is low will be very high. For example, 1m. curies might give a yield of 3 tons to 30 tons of product with low $G$ value in each year, and so the cost would be high, so that manufacture by such a method would be only justified if the product was normally very expensive, or if it was not obtainable by other means.

In the case of fission energy, it has been shown that the rate of chemical production is a direct function of the product $Gx$, where $x$ is the fraction of the total fission fragment energy deposited in the reactants. Thus, the cost of the process will be inversely proportional to $Gx$, so that in order to keep costs as low as possible the product $Gx$ must be minimized. For example, in the case of the radiation-induced conversion of air into nitric oxides, the $G$ value is about 10, and $x$ about 0.3, so that $Gx$ is about 3.0.

High values of $x$, *i.e.*, good energy transfer to the reactants, are obtained when the system is homogeneous, the reactor fuel being mixed with the chemical reactants, and this has given rise to one concept for a chemical reactor of the fluidized type, as we shall see later.

## Low Range a Problem

If fission energy is to be used for initiating chemical reactions, it must be borne in mind that more than 80 per cent. of fission energy is carried by the fission product particles, and that this energy is normally converted into low grade heat before it can be used. This makes for low efficiencies in electricity production from nuclear fission. The range of fission fragments is very small; of the order of 2 cm in gases, and only about 0.01 mm in fuel elements, It is very obvious, then, that if this high

grade energy is to be utilized, it becomes necessary to allow the fission fragments to come into contact with the chemical reactants almost immediately after the fissions have occurred, and this means that the layer of fuel must be not more than 0.002 mm thick. The amounts of energy which would then be available are very high, of the order of 1,000 to 10,000 times those obtainable in commercial accelerators.

### Too Thin, Too Unstable

Now, modern plate type fuel elements are quite thin, but even if unclad would allow only less than 4 per cent. of the fission energy to be used for chemical reactions. Were the elements to be designed with a very fine coating, more energy would become available, even up to perhaps 25 per cent., but the fuel elements would be extremely weak in the mechanical sense, and quite unable to stand up to the passage of the reactants.

Again, the yields for a single passage of the reactants through the reactor core would be very low, only up to 0.5 per cent. in the case of liquids, and about one-tenth of this for gases. Multiple passes might then be required unless the product is very easily separable from the reacting materials.

The use of fluidized fuel-reactant mixtures has already been mentioned. Another possibility is to incorporate enriched uranium in glass, and to extrude this in the form of very fine fibres. With fibres about 0.002 mm thick, and with gas pressures of the order of a few hundred atmospheres, up to 50 per cent. of the fission product energy might be utilized. Other workers have suggested that the fissile material might be adsorbed on substances of very high surface area; charcoal might enable 50 per cent. utilization of energy, or alumina about 20 per cent.

### No High G Values Yet

The energy release from each uranium fission is $2 \times 10^8$ev, and in order to compete with conventional chemical manufacturing methods, the irradiation process would need to produce at least 100 molecules/100ev. Such a high $G$ value is not yet recorded in gaseous reactions, and the maximum yield is likely to be only 2-3 per cent., although increased by the use of pressure.

Chemical reactions induced by radiations and charged particles can be admirably studied by means of high energy linear accelerators, even though this machine may not necessarily be the best tool for production purposes. One accelerator built at the Argonne National Laboratory, U.S.A., for this purpose, can produce a 280 ma beam of electrons, equivalent to $1.8 \times 10^{18}$ electrons/sec, with energies from 1MeV to 18 MeV. Normally the beam must be diffused over a wide area, or the windows of the machine would be melted. This machine, however, can produce a beam only 1 cm across, and an intensity of 200,000 rad can be produced in a single pulse, repeated 800 times/sec. This work has been supported by the Allied Radiation Corporation of California.

### Work Described at Geneva

At the International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958, J. K. Dawson and J. W. T. Merewether presented a paper on radiation-induced reactions, and described experimental studies of some of these. Since a reactor was not convenient for this experimental work, studies were done with simple fission product sources.

Irradiation of gases was carried out within a platinum cylinder coated with a layer of uranium oxide 1 micron thick, inside silica ampoules and in an autoclave of stainless steel or titanium. It was found that the experimental results best fitted a square relationship, $E_x/E_0=\left(1-\frac{x}{L}\right)^2$ where $L$ is the maximum range of the fission product fragments, $x$ the distance actually travelled, and $E_0$ and $E_x$ the energies corresponding to these two distances respectively.

### Best for Solids

The square law fitted the results best in the case of solids. It was possible to calculate $F$, the fraction of the fission fragment energy deposited outside a small sphere or an infinitely thin slab undergoing fission. Experiments confirmed the applicability of the square law energy loss for solids in which there is isotropic generation of fission fragments. In gases, the value of $F$ was best obtained by using the mean values calculated from the square law equation and the linear law equation $E_x/E_0=\left(1-\frac{x}{L}\right)$.

Sometimes untoward complexities are found. In the irradiation of air for production of oxides of nitrogen, for example, it was found that the $G$ value was 0.8-0.9 when the gas was at normal pressure, and when the fragments were depositing the majority of their energy in the gas phase. This nitrogen fixation was not, in fact, in step with calculated values of energy deposition of energy by the particles for a given length of path.

### When Energy is Highest

The effective $G$ value was found to be very low in the early part of the path, rising to 8-10 near the end of the particle's range. The density of ion formation/cm of track is much lower for fission fragments at the end of their range. The fission fragments lose most of their energy by gas ionization in the first 1.5 cm of their path, and the loss of energy as a result of excitation and direct ionization with kinetic energy transfer becomes important when the energy on the fragment is reduced to about 5 MeV in a gas such as nitrogen; these processes start to become important when the fragments have travelled more than about 1.6 cm.

Such considerations must be borne in mind when it is a question of the design of apparatus for high yield chemical reactions, since it is necessary to ensure that the final part of the particle range is within the gas to be irradiated. It should be pointed out, however, that this does not automatically apply to all gases.

One of the gaseous reactions in which there has been considerable interest is the formation of water-gas, since this is an important industrial product.

The possibility existed of converting water-gas into useful organic materials by means of irradiation-induced reactions. Enriched uranium oxide was brought into contact with mixtures of hydrogen and carbon monoxide (*i.e.*, water gas) in Harwell's BEPO.

Although the presence of formaldehyde (HCHO) and its polymers could not be established, the formation of methane and carbon dioxide was confirmed in the gaseous

phase. The formation of the $CO_2$ increased linearly with radiation dose, up to $6 \times 10^{21}$ ev of absorbed energy, but there was no correlation of yield with the energy deposited in the $U_3O_8$ film or the total fission fragment energy. The $CO_2$ formation was found to increase with CO pressure up to about 1.4 atmosphere, but the hydrogen pressure had no effect. It seemed that either carbon or some carbon suboxide was deposited from the gas phase during the irradiation, and this gave rise to further reactions. Possibly the carbon suboxide reacted with uranium oxide $U_3O_8$ to form $UO_3$ and carbon, but the diffraction patterns of the products were not those of any known compounds.

In the gaseous phase there were small amounts of methane and formaldehyde formed, and the *G* values for these depended on the ratio of the reactant gases. However, the *G* values were far too low for further work on this system to be worthwhile, and this highlights one of the principal features of work of this type.

Gamma radiation offers distinct possibilities, even if the chemical reactor is not very promising. One method by which gamma radiation might be applied to chemical processing would involve the continuous circulation of liquid sodium through the core. The intense gamma radiation of the sodium-24 would then become available in a portion of the plant adjacent to the actual reactor. Many reactions induced by gamma radiation have been studied, and some of these could well be of major industrial interest. For example, benzene is oxidized by air in the vapour state, with formation of phenol, but the yield is low. However, if the reaction is carried out in aqueous solution, and in the presence of traces of ferrous ions, the yield is much improved, especially if oxygen is added.

### *Benzene into Aniline*

In a similar way, benzene in aqueous solution containing ammonia, is converted in aniline, with reasonably high yield, again increased by addition of oxygen and ferrous salt. Benzene, on irradiation with gamma rays in presence of chlorine, is converted by a chain reaction, and in good yield, into the gamma isomer of hexachlorobenzene, a well-known pesticide. One advantage is that the product is still transparent to gamma rays, so that the reaction may be carried to completion, whereas when ultra-violet light is used for this reaction, the product is opaque to the radiation, and slows down reaction.

There is also scope for the application of irradiation methods in the manufacture of certain other chemicals. For example, mention has already been made of the formation of hydrogen peroxide as a result of the free radicals produced in water by radiations. This is very much in its infancy, but there is hope that a large-scale method might be developed. Hydrogen peroxide has a great number of uses, one of the latest of which is in the fuel systems of rockets and space projectiles.

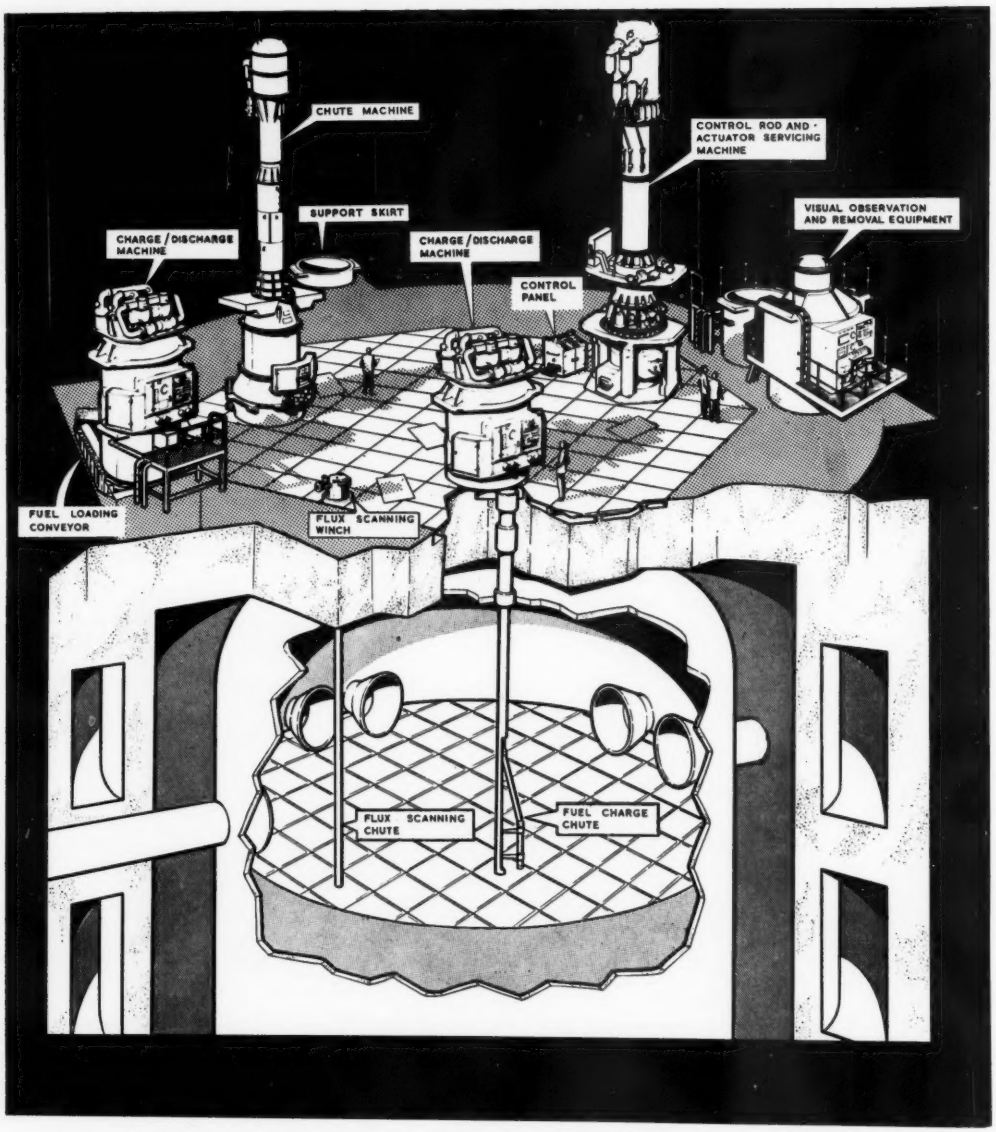
In this same field there is also interest in hydrazine, which can also be formed by the irradiation of ammonia, as a result of the breakdown of the $NH_3$ molecule to form the $NH_2$ and H radicals, the $NH_2$ radicals then combining to form the $N_2H_4$ or hydrazine molecule.

(*To be Continued*)

# Twenty-three U.S.-EURATOM R. & D. Projects

THE U.S.-Euratom Joint Research and Development Board report that 23 contracts for research and development work totalling approximately $3,500,000 were authorized within the Community and the United States during the last six months of 1959. During that period the Board concentrated its efforts chiefly on proposals related to the nuclear fuel cycle. Fourteen Community and eight United States organizations are represented by the work authorized, much of which involves close collaboration between Community and U.S. industrial groups. Approximately half of the funds have been awarded to Community and half to United States groups. The organizations, together with the nature of their research and development proposals, are as follows: Study project on the extrusion of uranium oxide, submitted by Compagnie Industrielle des Céramiques Electroniques (CICE), subsidiary of Compagnie Générale de Télégraphie Sans Fil (CSF), in collaboration with the Commissariat à l'Energie Atomique (CEA), France; Diffusion of fission gases in reactor materials, submitted by Hahn-Meitner Institut fuer Kernforschung, Germany; Zirconium alloys containing NB or SI, in view of their utilization in water-cooled reactors submitted by Metallgesellschaft, Germany; Improvement of sintering of uranium oxide by the addition of metal oxides (DI, TRI or pentavalent) in order to improve the thermal conductivity submitted by Compagnie Générale de Télégraphie Sans Fil (CSF), in collaboration with the Commissariat à l'Energie Atomique (CEA), France, Reprocessing of irradiated uranium, submitted by Centre d'Etude de l'Energie Nucléaire (CEN), Société Belge de l'Azote et des Produits Chimiques du Marly (SBAPCM) and Société d'Etudes de Recherches et d'Applications pour l'Industrie (SERAI), Belgium; Corrosion problems, submitted by Centre Belge d'Etude de la Corrosion (CEBELCOR), Centre d'Etude de l'Energie Nucléaire (CEN) and Société d'Etudes de Recherches et d'Applications pour l'Industrie (SERAI), Belgium; Fuel element fabrication with oxides, mixtures of oxides, cermets and UC, employing the swaging techniques and other methods of compression, submitted by Degussa, Germany; Dimensional changes in zirconium alloys by temperature variations; submitted, by Degussa, Germany; Dimensional changes in zirconium alloys by temperature variations, submitted by Metallgesellschaft, Germany; Stability of certain reactor structural materials, submitted by Metallgesellschaft, Germany; Treatment of water and radioactive residues, submitted by Centre d'Etude de l'Energie Nucléaire (CEN) and Evence Coppée, Belgium; Uranium carbide and mixed carbide fabrication; UC cermets fabrication; corrosion improvement and study of properties, submitted by Degussa, Germany; Development of clad ceramic plate fuel elements by spraycoating techniques, submitted by American Standard, U.S.A; Boiling heat-transfer and void-distribution studies with water and organic moderator coolants, submitted by Battelle Memorial Institute, U.S.A; Study of phase relationships in the U-C-O-System, submitted by North Carolina State College, U.S.A; Diffusion of fission gases through uranium oxide and fuel element claddings, submitted by Radiation Applications Inc., U.S.A.; Improved zirconium alloys, submitted by Armour Research Foundation of Illinois Institute of Technology, U.S.A.; Investigation of the technical feasibility of cold extrusion for zircalloy-2 tubing production, submitted by American Standard, U.S.A.; High performance $UO_2$ programme, submitted by GEC, U.S.A.; Development of uranium monoitride as an improved fuel for slightly enriched uranium power reactors, submitted by Battelle Memorial Institute, U.S.A.; Steam sintering of $UO_2$, submitted by FIAT, Italy and Westinghouse, U.S.A.; Swaging or uranium dioxide, submitted by FIAT, Italy and Westinghouse, U.S.A.; Fission gas release from uranium dioxide, submitted by FIAT, Italy—Westinghouse, U.S.A.; and Study of light water-steam mixtures as reactor coolants and their applicability mainly to water-moderated reactors, submitted by Centro Informazioni Studi Esperienze (CISE), Italy, Ansaldo, Italy, and Nuclear Development of America.

# *Berkeley N-Station's*
# CHARGE FACE MACHINERY




**Artists' impression of the charge face of a Berkeley reactor and top of pressure vessel fitted out with fuelling and servicing equipment**

UNLIKE the Calder Hall and Chapelcross reactors, the reactors in a commercial nuclear power station have to be refuelled while operating at full pressure and load. This necessitates the use of special equipment which enables near-spent fuel elements to be removed from the reactor core and replaced with new ones without the performance of the reactor being affected, and without there being any release of radioactivity.

Equipment for this purpose to be used at the 275 MW Berkeley nuclear power station is being manufactured by the John Thompson Ordnance Co., a member firm of the John Thompson Group, which with Associated Electrical Industries Ltd., is building the station. They are also making the associated charge face equipment such as machines used for removing control rods and actuators from the core and inspection equipment.

In each of the two Berkeley reactors there will be 42,575 fuel elements. These will be dispersed throughout the core in 3,000 fuel channels, 13 elements to each channel.

Access to the fuel channels from the top of the reactor, or charge face as it is called, is provided by means of 54 standpipes disposed on a square lattice of 32 in. pitch. Each standpipe is fitted with a gas valve and serves 64 fuel channels.

Before any fuel elements can be inserted into or removed from the channels, a connection between the top of the channel and the appropriate standpipe has to be made. This is achieved by means of an articulated chute, about 40 ft long, which is dropped into position by means of a special piece of equipment called the chute machine. The chute is identical in cross section to the fuel channel and by means of an articulation it can be indexed into contact with any one of the 64 channels associated with one standpipe.

### Machine is Pressurized

The chute machine consists principally of a grab and winding mechanism for raising and lowering the chute; a rotating three-chambered magazine to store two chutes; and a mechanism for operating the grab. All these are contained inside a pressure vessel which is pressurized so that when the machine is connected to the reactor core there is no loss in the reactor operating pressure.

The vessel itself is contained within shielding to protect operators from radiation. A valve at the foot of the machine is fitted to contain the gas included inside the machine when it is removed from the standpipe.

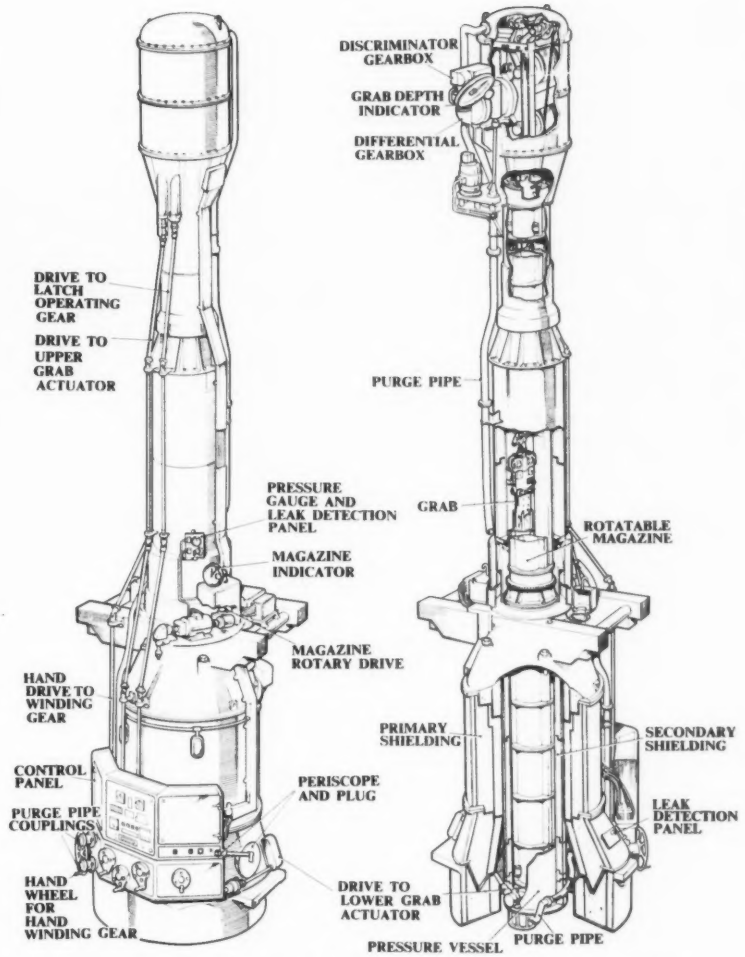
Each reactor will be provided with two chute machines. One will be a spare replacement and will not be fitted with shielding while out of use.

The chute machine which is about 55 ft high is moved about the reactor charge face by means of the charge face crane. It is supported in its position over a standpipe on what is called an operational skirt.

This is a 2 ft 6 in. high ring unit containing 16¼ in. of borated polythene and 3 in. of lead within its walls. Header tanks connected permanently to the polythene-filled ring accommodate the expansion and contraction of the polythene mixture under extremes of temperature.

When the skirt has been positioned over the standpipe and the chute machine lowered into place a seal is made and the machine pressurized. A valve is opened and the grab lowered to engage the shield plug placed in the standpipe. This is lifted out, secured in one chamber of the three-part magazine of the machine. The grab is released and the magazine rotated and the grab engages the chute which is to be lowered into the standpipe.

After the chute is lowered the articulated end is moved into position over the fuel channel to be unloaded. The grab is released and withdrawn, the valve shut and chute machine purged of gas and removed. The fuel channel elements in the channel can now be removed.




**Chute machine from the outside (*left*) and how it is internally constructed (*right*)**

### Removal and Insertion

Removal of fuel elements and insertion of new ones is carried out by means of charge/discharge machines. These comprise in essence a winding mechanism controlling a grab which can engage and disengage fuel elements as required and a rotatable magazine capable of accommodating 13 fuel elements. Shielding plugs are fitted above and below the magazine to reduce the effect of radiation; the bottom plug contains a rotary shield to seal-off the channel used by the grab.

### Also Pressurized

At the bottom of the machine is a gear box for controlling the fuel element chute when it is in the reactor.

All this equipment is enclosed in a pressure vessel shielded on the outer side to give necessary protection and built to withstand the working pressure of the reactor.

The machine can be controlled automatically by means of relays, uni-selector switches and a selective card system. A fully comprehensive system of interlocks prevent actions

which might cause damage or prove dangerous.

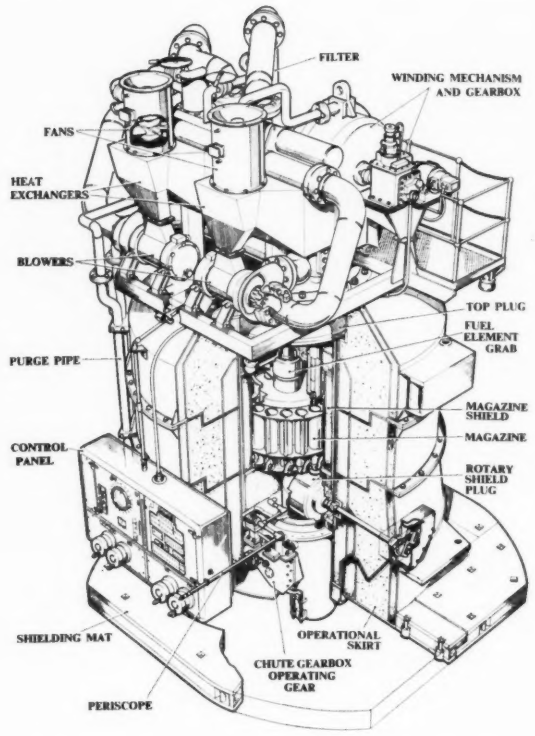
The machine is fitted with a cleansing and cooling system normally using air but substituting $CO_2$ when connected to the reactor.

Each reactor charge face will be equipped with three charge/discharge machines; one for unloading fuel channels, another for loading, and the third to act as a standby.

## Stages in Removal

Like the chute machine, the charge/discharge machine which weighs 100 tons is moved about by crane and is supported in position over a standpipe by means of a skirt. When in this position, it is pressurized, the valve opened and the chute operation gear lowered to engage with the head of the chute. The grab is lowered to the bottom leg of the chute, the leg is raised, the grab lowered to engage the fuel element, the grab is operated, element lifted to the bottom chute leg, weighed, chute collapsed, element raised to magazine, latch lowered, element lowered, grab disengaged, grab raised, magazine indexed—and so the cycle starts again until all 13 fuel elements are removed and accommodated in the magazine.

The machine is then sealed off and purged and transferred to the discharge well. Here the fuel elements are discharged into a shaft prior to being removed to the cooling pond. The machine is supported over the shaft on a what is called the "discharged well skirt." This is 2 ft 6 in. high and contains 4 in. of lead and $19\frac{1}{4}$ in. of iron shot concrete in its walls.



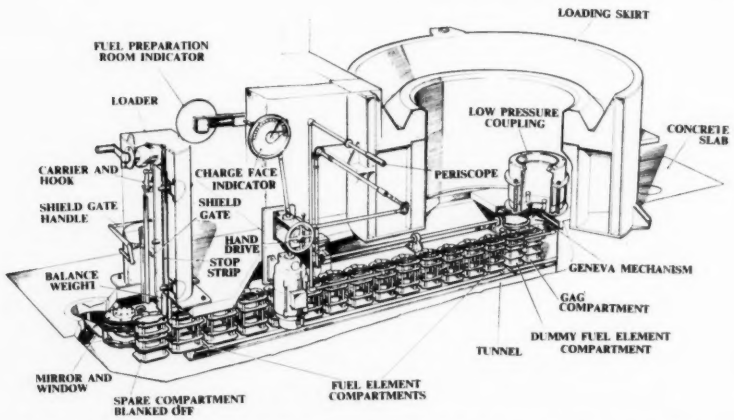

**Cutaway diagram of charge/discharge machine. There will be two of these in operation on each reactor. A third machine will be in position as a standby**

The insertion of new fuel elements into the empty channel follows a sequence of events the reverse of those in the unloading operation. The machine itself is filled with new elements by means of the fuel loader and conveyor. This consists of a loading skirt, low pressure coupling and loading conveyor and its loader.

The conveyor consists of two horizontal endless chains passing around four sprocket wheels, each pair on a vertical axle. Supported between the chains are 16 compartments of approximately the same section as the tube used in the charge/discharge machine magazine. Elements are held in the bottom of the compartments by means of stops, and are lowered into the compartments by means of a loader and removed from them by the grab in the charge/discharge machine.

When the chute and charge/discharge machines are not in use they are supported on parking skirts. There are two types of these, one without shielding and the other containing 8 in. of lead and $11\frac{7}{8}$ in. of iron shot concrete within its walls.

After the reactors have been operating for two years the core will be replenished with new fuel at the rate of 10 channels a week. Unloading of one channel takes about 45 min.




**Equipment for loading the charge/discharge machine with fuel elements. The latter machine is held in position over the loader by means of a loading skirt**

## Other Uses

In addition to being used for refuelling, the chute machine can be used for the positioning of chutes used for other purposes. There are, for instance, the flux scanning chute which is used in conjunction with the flux scanning winch, the thermocouple chute, used in conjunction with its own winch vessel; metals sample chute; and graphite sample trailing thermocouple chute. It can also

be used for raising and lowering the reactor periscope, standpipe plug, and charge standpipe sealing plug.

Control rods, control rod actuators, gags, fixed absorbers, etc., are removed from the core by means of the control rod and actuator servicing machine (CRASM). This is very similar in shape and appearance to the chute machine and consists basically of the same equipment. It is in two main sections—the magazine section which is 40 ft high and 5 ft in diameter and weighs 85 tons, and the skirt or support section, which is 8 ft high and 10½ ft in diameter and weighs 65 tons.

### Clean and Unclean Sections

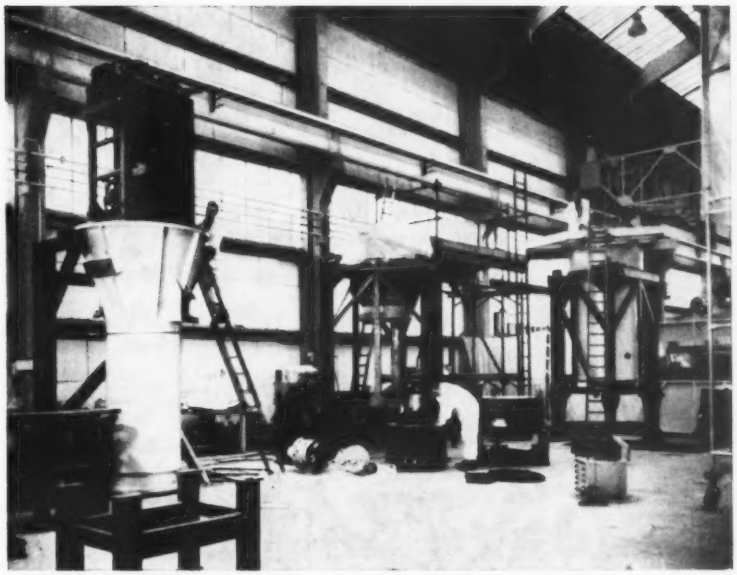
The magazine section consists of a pressure vessel containing four magazines each with its own grab and winding gear. One magazine is for clean (uncontaminated) control rods, another, dirty (contaminated) control rods, the third for clean actuators, and the last dirty actuators. The pressure vessel is itself surrounded with shielding and the whole can be lifted away from the skirting section.

This section is also pressurized and it houses various tools by means of which the actuator can be separated from or connected to its control rod. Two periscopes are provided to assist in these operations and there are a rotary shield and two flap valves to make a seal against radiation and pressure. The skirt section can be used in conjunction with the visual operation and recovery equipment.

This latter equipment is designed to enable a television camera to be lowered into the reactor during a shut-down under pressurized conditions. Attached to the camera will be a pair of remotely controlled tongs or another tool, and the machine will incorporate means of changing this tool for another of a selection available.

### These Problems Overcome

The design and production of the Berkeley charge face equipment has involved considerable problems and difficulties which have been overcome only by extensive research and experiment. All the equipment must be not only heat resistant and pressure-tight, but also immune from neutron activity and able to withstand gamma radiation. The materials used in the machinery must be compatible and in this direction difficulties were encountered with such items as rotating bearings. When welding the assemblies the difference between stainless steel and mild steel in clearances had to be taken into account.



**Shop at the Wolverhampton works of the John Thompson Ordnance Co., Ltd., where the Berkeley charge face equipment is being constructed**

Extra special care had to be taken with the design and manufacture of the remotely controlled equipment which when once put into operation will not be able to be normally maintained, and therefore must be absolutely reliable in operation. Lubrication in some of the equipment is virtually impossible because of the effect of radioactivity and high temperatures on normal lubricants.

There is also the question of the very high tolerances to which the equipment has to be manufactured to be taken into account. Some idea as to the accuracy needed is illustrated by the fact that the fuel chute has to select one fuel channel out of 3,000 from a distance of 40 ft within ±0.22 in.

## Trade Literature

**"World of Meaning,"** published by S. Smith & Sons (England), Ltd., describes in detail how the many products of the firms that belong to the Smith organization are used. Among these are such products as K.L.G. plugs, Bluecol, Kelvin Hughes instruments and Unitubes. The book also contains a section on the research facilities of the organization and on the recruitment and training of staff. The text throughout is intelligently written and provides rather more than just a "blurb" for the Smith products—it does, in fact, form an introduction to the practical application of instrumentation. The book is lavishly produced and the first part is profuse with beautifully-reproduced wash paintings. "World of Meaning" would make a very acceptable gift to the knowledge-seeking schoolboy.

**"Batching Plant,"** published by Thos. W. Ward, Ltd., of Sheffield, illustrates the activities of the firm's materials handling division. Specifications of various types of plant are given and there are illustrations of installations already in operation.

**"Stone's Bronzes Manual,"** published by J. Stone & Co. (Charlton), Ltd., has been compiled for the guidance of designers in choosing the right materials for any particular job. It is a neat little loose-leaf book full of useful tables and diagrams interspersed with odd historical notes.

**"B.K.L. Tubend Welding Fittings,"** published by B.K.L. Alloys, Ltd., of Birmingham, is a catalogue of the firm's range of elbows, return reducers and caps. Tables give comparisons between British and American standards and there is a section dealing with materials suitable for low temperature service.

**"Ilovac"** is the name given by Wakefield-Dick Industrial Oils, Ltd., to their new mobile conditioning plant for transformers and transformer oil and they have recently published a booklet under this title describing it. The plant, by removing air, water and solid contaminants from transformer oil, perfects the physical condition of the oil, thus ensuring the highest possible degree of safety when the transformer is on load.

# JANUS

## *The Two-faced Reactor*

### DESIGNED EXCLUSIVELY FOR BIOLOGICAL RESEARCH

ARGONNE National Laboratory, Lemont, Illinois, are to build a nuclear reactor with two radiation faces. It is to be used exclusively for biological research and will initially be used to study the effects of both high and low doses of fission neutrons in small animals.

The reactor, named JANUS after the two-faced Roman god, is expected to be ready for operation in early 1961. Estimated cost of the project is $560,000.

" As far as we know, JANUS will be the first nuclear reactor anywhere to be used solely for determining the effects of fission neutrons on biological specimens. It will not be a reactor for medical treatment, such as the one at Brookhaven National Laboratory," says Dr. Austin M. Brues, Director of Argonne's Division of Biological and Medical Research. " However," he added, " the studies it will make possible may give important leads in the search for medical uses of reactors."

#### *Previous Biology Work*

For a number of years, in co-operation with other AEC facilities, the Biological and Medical Research Division has been investigating early and late effects of radiations in mammals given in widely differing patterns and dose rates. The Division has two specially-constructed rooms where mammals are exposed to high and low levels of gamma radiation from cobalt-60 sources.

Work with fission neutrons by Argonne was first carried on at the Laboratory's early research reactor, CP-3, located near the present Argonne site. When the Laboratory built the Argonne Heavy Water Research Reactor CP-5 in 1954, a special radiation chamber was installed to allow neutron irradiation of biological specimens.

The neutron biology work at Argonne has been centred on three principal problems:—

(*a*) The differences in time and cause of death following neutron and gamma irradiation;
(*b*) Deviations in additivity of neutron and gamma radiation in inducing speedy death; and
(*c*) The differences in recovery rate following neutron and gamma irradiation.

Dr. Brues says: " The JANUS reactor will make it possible to carry out, simultaneously, experiments at much higher and lower neutron dose rates than previously possible."

#### *Effects on Plants, too*

Argonne biologists also expect to use JANUS for other research projects such as determination of the effects of neutron irradiation on viruses, seeds, spores, and many other forms of plant and animal life.

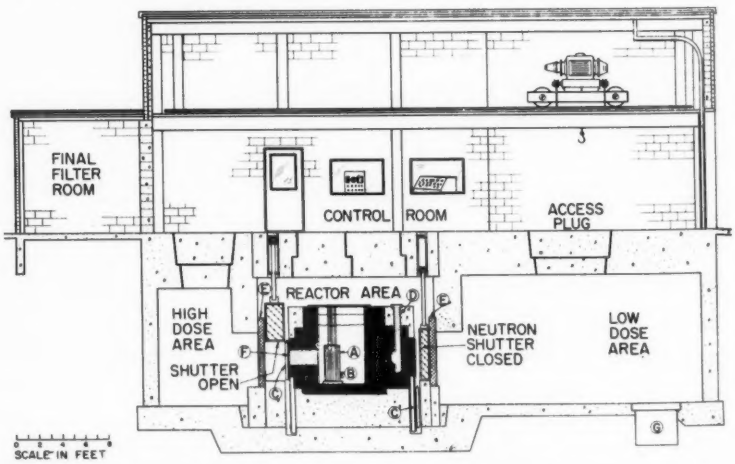
JANUS is designed to operate for extended periods of time at powers of from approximately 1 to 200 kW. It will be located below ground level, with a large radiation room fanning out from each of its two faces, one for high-level radiation exposures, and the other for weaker, low-level exposures. Above the radiation rooms and the reactor will be a one-storey structure housing the JANUS reactor control room and a service area.

Concrete floor plugs in this one-storey structure will permit complete access to the reactor and the radiation rooms. A 10-ton overhead crane will be employed to raise the plugs and to lower heavy equipment to the reactor level. A second control console, governing mechanical operations of the facility, will be located at the level of the reactor.

The room where high-level irradiations will take place will allow specimens to be exposed at a dose rate of approximately 100 rads/min. A 16-in. square plug in the face of the reactor will allow access to even higher neutron intensities.

#### *Almost Continuous Operation*

Low-level irradiations will take place in a room on the opposite side of the reactor from the high-level room. Neutron dose rates in the low-level room will range from 0.1 to 50 rads/week. The room will be operated for as many as 16 hours a day, six days a week, providing



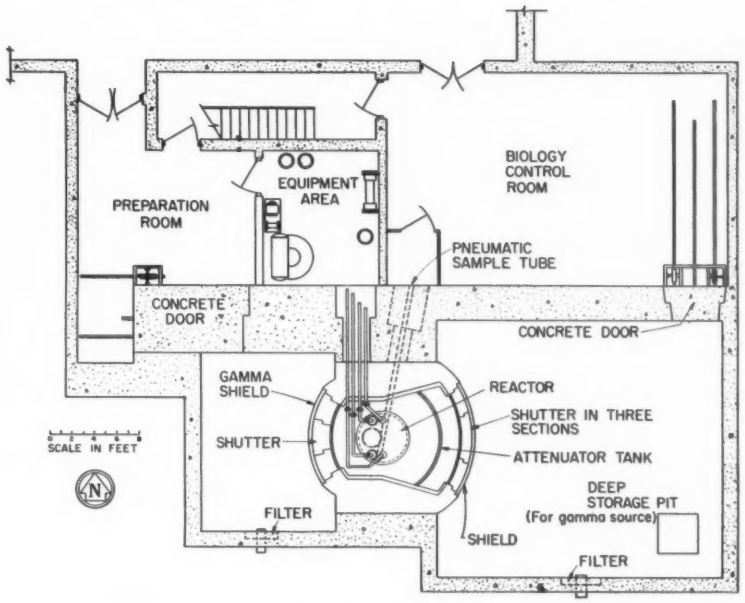

**Sectional drawing of the reactor building.** Key:—A—fuel core, B—pneumatic sample tube, C—convector plates of uranium, D—neutron attenuator tank, E—lead gamma shields, F—16 in. square hole in thermal column on high dose side, normally filled with graphite, G—3 ft deep storage pit

lifetime neutron exposure for small biological specimens.

Closed circuit television in the control room at the level of the reactor will permit the operators of JANUS to observe their biological specimens during irradiation.

An additional facility, a " rabbit " or pneumatic pressure tube, will be provided so that small samples of various substances can be irradiated within the reactor tank. These samples will be shot into a 2 in. diameter sealed tube within the tank and withdrawn by suction. The rabbit facility will be employed to make radioisotopes that have very short half lives.

The reactor will be a light water moderated-cooled reactor fuelled with enriched uranium. There will be 6.6 lb of this arranged in 19 assemblies to form a 16 in. diameter core. The length of this core will be about 26 in.




**Plan of reactor floor**

## *Varied Neutron Intensities*

The fuel core of JANUS will be located slightly off centre in the reactor tank to provide different intensities of fission neutrons in the two irradiation rooms. The tank itself will be approximately 4 ft in diameter and 7 ft high. It will be made of $\frac{3}{8}$ in. thick aluminium. The tank will be sealed gastight by a gasketed cover. Ordinary water, the moderator-coolant, will circulate upward in the tank through the fuel assemblies, then through a heat exchanger. A portion of the water will be constantly circulated through an ion exchange column to remove impurities.

To reflect escaping neutrons back into the reactor, a layer of graphite ranging from 1 ft to 5 ft in thickness will be built around the tank. With the exception of its two radiation faces, the reactor will be heavily shielded by dense concrete.

Fuel assemblies in JANUS will be similar to those employed in the Argonne Heavy Water Research Reactor CP-5 (Chicago Pile 5). Each will be 3 in. in diameter and will consist of enriched uranium encased in three concentric aluminium tubes.

So that JANUS can be operated for as long as three years without a reloading of nuclear fuel, more enriched uranium will be built into the fuel assemblies than will be necessary to run the reactor at its rated power. To keep down the rate of fuel consumption, strips of boron-aluminium will be placed inside each fuel element to stop excess neutrons. These strips will be removed as the uranium fuel is used up.

The high-dose irradiation room will be 16 ft long, 12 ft wide and 8 ft high. A convex (bowing outward) radiation face approximately 3 ft high and $6\frac{1}{2}$ ft wide will allow neutrons to escape from the reactor into the room. The distance from the centre of the JANUS fuel core to the face opening will be approximately 5 ft.

A movable converter plate of 1 in. thick uranium placed over the high-dose face will raise the energies of neutrons produced in the reactor from relatively low (or " thermal ") to high (or " fast ") velocities.

## *Shielding Arrangements*

To prevent radiation from coming into the room, a 20 in. thick shielding shutter can be lowered in front of the high-dose face. The shutter will be operated in three independent sections so that only a portion of the neutron beam can be allowed to escape from the reactor. A lead gamma shield, 6 in. thick, will be installed across the high-dose radiation face in front of the shutter.

On the high-dose face a 16 in. square hole will pierce the graphite thermal column of the reactor. Available for special-purpose irradiations, this hole will normally be packed with graphite.

The low-dose irradiation room will be 26 ft long, 24 ft wide and 11 ft high. A larger convex radiation face, approximately 3 ft high and $10\frac{1}{2}$ ft wide, will allow neutrons to escape from the reactor into the low-level room. The distance from the centre of the fuel core to the low-dose face opening will be about 7 ft.

A movable 1 in. thick uranium converter plate will also be placed over the low-dose face. The room will have a 10 in. thick shielding shutter, also operated in three independent sections. When all three sections are in place, the converter plate will be removed. A 4 in. thick lead gamma shield will be held in place across the face in front of the shutter.

An aluminium tank, 4 ft high, 10 ft wide and 4 in. deep, will be installed on the low-dose side of the reactor. The tank has been designed so that it can be filled with a boric acid-water solution to attenuate the neutron beam, if necessary.

The low-level room of JANUS will have provisions for later use as a gamma irradiation chamber, with or without the addition of neutrons from the reactor. For this purpose a 3 ft deep pit will be built into the floor of the room to hold a Co60 gamma ray source.

DESPITE France's Sahara episode, the nuclear accent this month is on peace! Last month I hinted at public ignorance of atomic matters, which is unbelievable in view of the vast publicity given to that branch of technology. Apathy, then, must be the reason, and yet the altruists continue to persevere. One recent effort, highly recommended, is a film entitled "Power Among Men," made by United Nations, and obtainable on loan from Contemporary Films, of London. In its 90 min showing, this film makes an honest attempt to demonstrate the futility of squabbling over scientific progress. We see a village rebuilt in Italy, a co-operative farm in Tahiti, and 17 nationalities trying to live amicably around the Canadian Kittimat aluminium industry. By way of lurid contrast we see Hiroshima victims and H-bomb trials. Then a bee-keeper protests to the director of the Jener nuclear establishment at Kjeller, Norway, because he thinks a cloud of radioactivity has killed his bees. He learns that like his protegees, uranium and atomic energy can be lethal, but that they are safe when properly handled.

* * *

A. F. Lowell, of Rio Tinto Mining Co., of Canada, Ltd., says that now that British and American military needs appear to have been almost met, this bidirectional flow of uranium must become multidirectional. Any country determined on a nuclear weapon programme could make its plutonium from readily-accessible natural uranium, and economics need not be a deterrent. Consequently the bilateral agreements, which allow any one country to buy just over one ton of uranium on conditions which most countries consider unreasonable, are unrealistic and are throttling Canada's chance to market the uranium which they are producing at the rate of 15,000 tons a year. Canadian producers are fed up with government restrictions.

* * *

On the single sheet of the first issue of "Trawsfynydd Site News" are given reasons why a nuclear power station is being built there, progress to date, and news of people concerned with the project. I was amused by the cartoon showing a a large building sinking into the ground at a rakish angle, and bearing the legend "Don't blame me. Go down to the site office and see R.C. He laid the corner stone." That's the spirit. I smiled, too, at the Blaenau Ffestiniog duck on the top of the crane.

* * *

I slipped up recently over Babcock and Wilcox! But now the American B. and W. has really done a deal, by which the great Italian shipbuilders, Cantieri Riuniti Dell' Adriatico, will build and sell merchant vessels powered by B. and W. nuclear units. The 100-year old CRDA, with 17,000 employees in four shipyards, intends to keep abreast of the times.

Nuclear vessels, however, are a bone of contention with the U.K. Chamber of Shipping, which asks for tax relief for the industry and more Government research spending, in order to hurry British nuclear marine developments. Certainly, money spent in this direction is more likely to see an earlier return in hard cash than similar amounts devoted to space rockets.

## 'NUCLEARIST' writes . . .

Now over to our British research centres for a little excitement. At Harwell, down a 40 ft evacuated tube on the side of a tower, $\gamma$-rays from radio-iron were allowed to fall in the earth's magnetic field, to be caught in the same nuclide. The rays would not be absorbed if, as Einstein forecast, a "red shift" should occur. Again, any relative movement between source and receiver nuclei would mean a Doppler effect on the wavelength, and consequent non-absorption. A radio-iron source at the centre of a rotor spinning at 30,000 rev/min had its emission received by the same nuclide at the periphery. In both experiments, made by the same team, results confirmed Einstein's predictions. One can imagine his smile of satisfaction were he still alive.

* * *

Nuclear Development Corporation of America is to study, as part of the U.S.—EURATOM programme, a new method of heat transfer which may raise reactor efficiency. In "fog-cooling," a mixture of high pressure steam and water droplets passes through the reactor, whose heat converts droplets into steam for the turbine.

* * *

The "School" of the Argonne National Laboratory's International School of Nuclear Science and Engineering has been changed to "Institute." With this change goes a broadening of curriculum, and a reduction in the basic nuclear theory. From 19 countries 51 graduates are enrolled for the first term, to enjoy the advantages of the best equipment and talent that Argonne can provide.

* * *

R. G. Scurlock, a Southampton physics lecturer, in a letter to the *Daily Telegraph* expresses concern at the idea of small nuclear reactors in British universities. He says they are dangerous and almost useless. He writes of X-ray and neutron fluxes, and appears not to know of shielding and monitors. Were there many with his caution and tenderheartedness concerning possible accidents, there would be no chemical experiments, high voltage equipment, or fast-moving machinery on the campus. This Job's comforter is hardly likely, however, to influence those with progressive ideas. American experience has shown that valuable work and training are possible with laboratory reactors.

* * *

Nuclear Enterprises (G.B.) Ltd., are to be congratulated on securing a contract, against American competition, for a piece of atomic machinery which might be called the housewife's dream since it can estimate the amount of lean in a piece of meat. Supplied to the U.S. Department of Agriculture's research station at Beltsville, near Washington, this machine contains a very large scintilation unit of the plastic type, which detects the gamma rays from potassium-40. Since this nuclide is mainly concentrated in muscle, rather than in fat, this machine can measure the non-fat portion of the meat. Since both dead and live meat can be examined, this device will be of interest to a wide circle of potential customers. But the housewife might just as well forget it, for it weighs 8 tons, and costs rather more than hubby would care to pay.

# NUCLEAR NEWS


- **DRAGON—U.S. Exchange** *(This page)*
- **New Beryllium Plant** *(Page 174)*
- **Royal Society Celebrations** *(Page 175)*


## DRAGON Matters

THE Board of Management of the OEEC High Temperature Reactor Project (DRAGON) has approved proposals for an exchange of information between the Project and the United States Atomic Energy Commission. The USAEC is developing a similar reactor to the DRAGON under a contract with the Philadelphia Electric Co., and General Dynamics Corporation. The Board of Management has also a £2.83m. budget for DRAGON during 1960-61. The budget comprises £950,000 for the reactor plant and buildings, £910,000 for extra-mural research and development, and £970,000 for the maintenance and work of the Project staff at Winfrith, the site of the reactor. The terms of office of the Board's chairman, Dr. Sigvard Eklund (Sweden) and vice-chairman, Sir William Penney (U.K.) have been extended for a further year. Following the sudden death of Freiherr Anselm von Ritter the Board has approved the appointment of Gianfranco Franco as chief engineer in his place.

## N-Energy in Farming

FOUR holders of IAEA fellowships have just graduated from a two-months' training course on atomic energy in agriculture at the Timiryazev Academy of Agriculture, Moscow, Russia. The course consisted of two parts. The first provided for training in basic nuclear physics, radiometry, radiochemistry, radiobiology, radiation hygiene and protection. The second part was devoted to the specialized training of students in the applications of isotopes and radiations in biology, biochemistry, plant physiology and selection, soil studies and plant protection. Besides a theoretical introduction, the course included practical work for the students. The IAEA fellows, who come from universities and agricultural establishments in Austria, Indonesia and Yugoslavia (2), are to continue their specialized studies at educational establishments in the Soviet Union.

## Sweden's Power Reactor

THE Swedish State Power Board has announced that it plans to locate its first full-scale nuclear power plant, the 100,000 kW R4-Eva, at Björnö, on the Baltic coast east of the city of Norrköping. The plant will be a surface structure, while the previously discussed underground location in central Sweden will be reserved for a forthcoming larger plant. The choice of a surface structure, the Board says, permits of greater flexibility in designing the plant and will also cut the building time. The plant is scheduled to go into operation in 1967 under a new agreement concluded between the Board and the Swedish Atomic Energy Co., AB Atomenergi. R4-Eva is the second industrial reactor in the Swedish atomic energy development programme based on the use of natural uranium as fuel and heavy-water as moderator, and with heavy-water under pressure as coolant. Atomenergi will be responsible for the design of the reactor in collaboration with two Swedish companies, Asea and Nohab. Major work on the building site is not likely to start until 1962.

## Accident Re-created

DOSIMETRY experiments are being conducted by the International Atomic Energy Agency to ascertain the exact neutron and gamma-ray doses received by staff at the Boris Kidric Institute at Vinca, near Belgrade, Yugoslavia, when the zero-power reactor there was out of control for a brief period during October, 1958. Responsible for the experiments are a team of experts under the technical direction of Dr. K. Z. Morgan, director of the Oak Ridge National Laboratory health physics division. It has been necessary to make certain modifications to the reactor to carry out the experiments. It will, for instance, run for 4 hr at a power level of about 5w and then for 1 hr at 500w. After completion of the experiments it will be restored as near as possible to the conditions at which it was supplied by the Yugoslav Nuclear Energy Commission to the Agency.

## Ergonomic Advice

INCLUDED in the advice given by the "human engineering" experts or ergonomists who have been making a study of the problems that will face the staff of nuclear power stations for the General Electric Co., were the following suggestions. Staff should spend only a proportion of their time watching dials and adjusting knobs. Seats in front of control panels should be designed so that the operator could either stand or sit. Monitoring of instruments should be kept to a minimum by the use of automatic alarm signals. All unnecessary dials should be eliminated. Staff should not be left alone. Control rooms should be small and compact. Reactor simulators should be installed to enable the staff to keep their minds agile by simulating emergency situations and other control problems. The experts came from Dunlap and Associates Inc., of Stamford, Connecticut, and they presented a summary of their findings and recommendations not only to the GEC but also to representatives of the Central Electricity Generating Board, the UKAEA, the Department of Scientific and Industrial Research, and the Admiralty.

## Stereoscopic TV

AN advanced system of stereoscopic closed circuit television has been developed by EMI Electronics Ltd., to meet the requirements of nuclear plants and other establishments where dangerous materials have to be manipulated remotely. EMI's stereoscopic equipment utilizes the company's standard closed circuit units and consists of two camera channels mounted side-by-side and arranged to relay pictures on to two monitors. The pictures from these are then superimposed on each other by means of a mirror and polarized glass, to form a single image. When viewed with polarized spectacles this produces a realistic three-dimensional picture.

## *In Nuclear Japan*

**Japanese workmen (*left*) and women (*above*) prepare the site for the GEC designed A-station at Tokai-Mura**

## A.E.I. Plant for Canada

THE turbine generator division of Associated Electrical Industries Ltd., have received an order from Atomic Energy of Canada Ltd., for a 220 MW steam turbine-generator for the nuclear power project at Douglas Point on the eastern shore of Lake Huron. The value of the order is about £2m. Certain parts will be made in Canada. AEI is also supplying the 20 MW turbine-generator for NPD 2, the Canadian Nuclear Power Demonstration situated 150 miles up the Ottawa River.

## N-Farming Course

AN international training course on radio-isotope techniques for agricultural workers, jointly organized by the International Atomic Energy Agency and UNESCO in co-operation with the Ministry of Food and Agriculture of India, was recently held in Delhi; lasting for four weeks it was attended by 25 agricultural specialists from Burma, Ceylon, Pakistan, Thailand and India. The first two weeks were devoted to nuclear and health physics and dosimetry. During the second two weeks lectures were given on radiation cytology and genetics; radio-isotope techniques as applied to problems in soil fertility, fertilizer application and plant biochemistry; and radiation as a protective agent—applications in metabolic studies with fungicides, insecticides and herbicides, sterilization of insects and food preservation.

## Blood Radioisotope

A NEW radioisotope labelled form of the powerful heart stimulant adrenaline is now available from Tracerlab, of Waltham, Massachusetts. Adrenaline is a normal constituent of the blood, and its presence helps to regulate blood pressure. The new compound is chemically known as dl-Epinephrine-d-bitartrate, methyl C-14 and has a specific activity of 0.47 mc/mM. It is expected to be used in metabolism studies and studies of emotional stress.

## Scholarship Boys

THE first boys ever to be awarded scholarships by the Electricity Supply Industry are now nearing the end of their first university year. They are the successful candidates in a scheme introduced by the industry in England and Wales last autumn to help meet its growing need for highly trained scientists and engineers. Under the scheme, sixth formers intending to read for degrees in science and engineering were invited to apply for scholarships worth £450 a year at Oxford and Cambridge and £400 a year at other universities. The only " strings " attached to the award were that scholars would be expected to spend a period of training with the industry before going up to the university—possibly as little as six weeks—and to return to it for at least two years after taking their degree. Particulars of the awards were sent to public and grammar schools throughout Great Britain and about 350 applications were received. Following interviews, 45 scholarships were awarded, 19 of them by the Central Electricity Generating Board, which requires both scientists and engineers, and 26 by the 12 Area Boards.

### *New Field for Aircraft Firm*

**Britain's first large-scale plant for machining beryllium has been opened in Coventry by Sir W. G. Armstrong Whitworth Aircraft Ltd., a member of the Hawker Siddeley Group. It will produce beryllium components for the latest type of nuclear reactors. Because of the hazards associated with beryllium when it is in dust form the new factory contains pressure " shells " which are supplied with filtered and heated air which is changed every 3 min. All machining processes are carried out inside completely enclosed machines, provided with their own high speed extraction systems, a view of such enclosures being illustrated here. The whole building has been designed to reduce fire risks upsetting the health protection precautions. All furniture, apparatus and equipment is made of steel, and the building fabric is of fire-resistant materials**

## Mill now Store

A FORMER blanket and hosiery mill at Dalry, Ayrshire, is being rented by GEC Ltd., for the storage of graphite and other core components for the two reactors of the Hunterston nuclear power station. The mill is situated about 12 miles by road from the Hunterston site, in the centre of a small town. It consists of the Old Mill of four-storeys served by a central lift shaft, and the New Mill, a modern single-storey steel-framed brick building.

## New Canadian Centre

ELEVEN THOUSAND acres of land 60 miles east-north-east of Winnipeg, Manitoba, have been selected for the site of Canada's second nuclear research centre, Atomic Energy of Canada Ltd., have announced. To be known as the Whiteshell Nuclear Research Establishment, the new centre will start as a small unit but will expand as nuclear research expands and may reach a size comparable to that of the Chalk River plant, which has grown steadily since it was established in 1944. Some work on the Whiteshell site will begin next summer, but the building of a major research facility is not expected to start before 1961.

## Purification Plant Pact

AN agreement has been signed between Head Wrightson & Co., Ltd., and the Belco Division of Bogue Electric Manufacturing Co., U.S.A., which will enable Head Wrightson to design, engineer and build Belco water treatment and trade waste disposal plants throughout the world, excluding the North American continent. The American company has installed some of the largest demineralization plants in the world at chemical plants, oil refineries and at nuclear stations and Head Wrightson's existing interests in these fields will permit them to expand the services they now offer. The design and manufacture of this equipment will be handled by Head Wrightson Processes Ltd., who have moved to 20-24, Old Street, London, E.C.1. The headquarters of this company, which is also responsible for all Head Wrightson's nuclear research and nuclear power interests will be located at Yarm-on-Tees, Yorkshire.

## US-Canada Programmes

NEGOTIATIONS are taking place between the U.S. Atomic Energy Commission and Atomic Energy of Canada Ltd., towards an expanded programme of co-operation in the development of heavy-water moderated nuclear power reactors. In both countries there are broad research and development programmes in heavy-water reactor technology. Under construction in Canada are a prototype 20 MW power station and a 200 MW full scale station, both using heavy-water reactors. A 40 MW (thermal) organic cooled, heavy-water moderated reactor plant is planned for construction. In the States there is a heavy-water moderated prototype power station under construction, and several heavy-water moderated test reactors already in operation.

## Soviet Plant Examined

A RUSSIAN-BUILT thermoelectronic generator, used to convert heat from a kerosene lamp into electricity for radios in remote Asian areas, is being examined carefully by a group of scientists at The Martin Co., U.S.A., where similar " direct conversion " principles have already been applied to nuclear heat sources. The 20 lb Russian device has been in production for at least two years, but it was only after long and persistent efforts that Martin's Procurement Department managed to locate an export model in England. It cost $56. In the Russian generator, a series of thermocouples is arranged around the upper portion of a kerosene lamp. As each set of elements is heated at one end by the lamp, a small amount of electricity flows through the pair. Metallic fins remove the excess heat.

## 300 Year Anniversary

SIR CHRISTOPHER HINTON, KBE, FRS, chairman of the Central Electricity Generating Board, is to give one of the lectures arranged by the Royal Society for its Tercentenary Celebrations, July 18th-26th. His subject will be "The Evolution of Nuclear Power Plant Design." Another Tercentenary Lecture will be "The Study of Nuclear Interactions at Very Great Energies," by Professor C. F. Powell, FRS, Melville Wills Professor of Physics at Bristol University. Both lectures will be delivered at the Beveridge Hall, London University, on Wednesday, July 20th at 10.15 a.m. and 2.30 p.m. respectively. The celebrations, which will be attended by distinguished scientists and representatives of scientific organizations throughout the world, will include not only lectures and speechmaking, but visits to places of historic and scientific interest, a Christopher Wren Sermon in St. Paul's Cathedral (Sir Christopher was President of the Royal Society, 1680-1682), a special film programme and, on the social side, receptions by the Government, the London University, and the City of London, a Tercentenary Conversazione at Burlington House and a Tercentenary Banquet at Grosvenor House. The formal opening ceremony will take place in the Royal Albert Hall on July 19th. The Royal Society was founded during the reign of King Charles II and received a Royal Charter in 1662. It is the oldest established Academy of Science in the world.

## Curing by Irradiation

LONG-TERM possibilities of using massive radiation doses as a means of curing hides and skins are being investigated in experiments being carried out in the Egham laboratories of the British Leather Manufacturers' Research Association (BLMRA) in collaboration with the technological irradiation group of the Isotope Research Division, AERE, Wantage. Curing methods in this old-established industry have changed little in essentials for hundreds of years. After the animal has been flayed, immediate attention must be given to arresting the putrefaction which begins almost at once in the hide or skin and which is caused by bacterial action. At present there are two main methods of doing this. The material may simply be dried in the sun until it becomes hard and stiff, like a board. This method is often applied, especially to goatskins, in tropical countries. While it is effective, it suffers from the disadvantage that it lowers the potential quality of the finished leather. The other method, which has a number of variations, is to use salt. Since the BLMRA was founded in 1919, there has been much research into the best type of salt to use for different classes of rawstock and the best methods of applying it. It is generally agreed, however, that salting also has certain disadvantages, although it is greatly to be preferred to drying. The possibility of using radiation techniques in place of salting as a method of preservation was first considered by the BLMRA following the formation of the technical irradiation group of the U.K. Atomic Energy Authority in 1955. Only X-rays or penetrating gamma rays seem to be promising. The main advantages are:—1. Highly efficient inactivation of micro-organisms and other forms of life is possible; 2. The rise in temperature is small; 3. Appreciable thicknesses of material can be treated in diverse containers; 4. The process lends itself readily to continuous operation. The main disadvantages are:—1. The cost of the process depends upon the continuity of the process because the capital cost necessitates 24 hr operation; 2. The radiation dose which appears to be necessary (2½m. rads) causes some loss in strength of the skin fibres and a fall in shrinkage temperature. Such changes also occur to some extent in the conventional liming process and therefore may not necessarily be an objection. Current results indicate that 2½m. rads will be adequate. Some calfskins cured by irradiation by the UKAEA at Wantage have been processed in a tannery using a normal commercial tannage and have made reasonable leather. The scientists and tanners who carried out this preliminary experiment believe that the leather could have reached commercial standards, given suitable process modifications.

## Plans for Ispra

THE agreement for the establishment at Ispra, Italy, of part of the Euratom Joint Nuclear Research Centre recently signed by representatives of the Italian Government and the Euratom Commission will enable the Commission to start its research programme. It intends to carry out the major part of its research at Ispra in the next three years, but negotiations are continuing in the meantime with the Federal German and Dutch Governments for the establishment of other parts of the Joint Centre at Petten, north of Amsterdam, and Karlsruhe. The Ispra Centre, which is to be gradually transferred to Euratom, is to concentrate on research and development work in various fields of nuclear science and technology. In the transition period, its new test reactor will be used to carry out a programme drawn up by a joint Italian-Euratom board: priority will be given to the current programme of the CNRN (Comitato Nazionale per le Ricerche Nucleari), which will be undertaken in close collaboration with Italian research teams. This programme is mainly concerned with neutron and solid state physics and reactor calculations and metallurgy. In addition, work initiated by Euratom will be undertaken. This will include power reactor technology, research on instruments for use in reactors and in the nuclear industry generally, the chemistry of raw and worked materials, especially that concerned with highly radioactive products, specialist training and documentation. Under the agreement the Italian Government will provide up to $9m. for the construction of necessary buildings and a European School similar to that already established at Luxembourg. It will also make available at reasonable rents accommodation for the staff and families working at the Centre. The Euratom Commission will contribute about $24m. to provide the equipment and facilities (and possibly buildings) required by the Centre, with about $15m. for operating costs.

## Ship Unit Critical

THE core of the reactor for N.S. *Savannah* recently achieved a sustained chain reaction at The Babcock & Wilcox Co.'s atomic energy division laboratory at Lynchburg, Virginia, U.S.A. It is believed to be the first propulsion reactor power core known to achieve criticality before installation. The test confirmed nuclear design and engineering calculations, and provided first hand experience for the safe installation of the core aboard the *Savannah*. Weighing more than 15 tons, the core contains 32 fuel elements containing 4.2 and 4.6 per cent. enriched uranium. It was tested in a tank 9 ft in diameter and 17 ft high, filled with more than 10,000 gal of de-ionized water.

## Radiation Course

A SECOND course in the principles of radiation protection is to be held at the Reactor School, Harwell, from April 20th to June 29th. The syllabus will be similar in content to the first course held at the turn of the year, but will be modified in the light of experience gained from this course. The course is intended for graduates or people of graduate status who are taking up or have started to work on health and safety problems in the nuclear field. Three days each week of the course will be set aside for lectures and two days for experimental work and visits. The fee for the course is £250.

## Fuel for N-Sub

MALLINCKRODT Nuclear Corporation of St. Louis, U.S.A., are to manufacture and supply the uranium material for the H.M.S. *Dreadnought* reactor core. This is the first time uranium metal for a nuclear warship will be supplied by any commercial, non-government source, in the world.

### *The Goliath in Action at Hunterston*

# Westminster talks about...

*by Peter Lewis — Our Parliamentary Correspondent*

FOR extra-mural studies in nuclear technology there is much to recommend the House of Commons. MP's now bandy such words as kilotons, fission and fusion as if they were established parliamentary jargon, and seem well versed in the economics of slaughter, or as our great Cambridge astronomer-mathematician Mr. Hoyle once termed it, "extermination economics."

The Government's intention to take steps towards supplying nuclear weapons to the armed forces of Western Germany, provoked an interesting debate on the imponderables involved. The peaceful uses of atomic energy however, and the attendant problems were not entirely submerged, for while the Lords were discussing the Radioactive Substances Bill, Members in the Commons were hurling questions at Ministers.

## *Nuclear Shipping ...*

The ubiquitous **Mr. Marples,** Minister of Transport, has been grappling with a spate of questions on nuclear propulsion units for shipping. Asked by **Major Wall** (C., Haltemprice), when the Ministry would be placing an order for a prototype nuclear marine-propulsion unit, Mr. Marples answered by saying that tenders for such a unit had now gone out. **Mr. Willey** (L., Sunderland N.), who had previously asked for a statement on the whole subject, was clearly disappointed by this reply, and submitted that the Government should pay closer attention to the more advanced forms of reactors under examination by the Galbraith Committee, and would the Minister look into the matter again as this country appeared to be lagging in the international race for nuclear propelled shipping. Major Wall asked what the minimum time would be for getting such a ship into the water subsequent to the Minister's order for a prototype nuclear unit. While it was possible to have a ship equipped with a pressurized water reactor in service by 1964, Mr. Marples considered that delay would be worthwhile in order to secure the benefits from the use of boiling water or liquid moderated reactors.

**Mr. Hector Hughes** (L., Aberdeen N.), requested the names of the members of the consortium of shipowners, formed on the proposal of the First Lord, to arrange for the ownership and operation of the first British-built nuclear powered ship. In a written reply the Minister of Transport stated that no consortium had yet been formed, but only a committee to consider its formation. In reply to a further question by Mr. Hughes asking for information on the eight reactor systems that had been submitted to the Galbraith Committee and their individual estimated cost and power, the Minister said that three of the eight units would be available in the next few years. The Minister went on to say that, of the short-term types, the pressurized water system showed the least promise.

## *UKAEA Staff ...*

Wearing his hat as Minister of Science, **Sir David Eccles** gave the following information in reply to a question put by **Mr. Warbey** (L., Ashfield). The table shows a categorical breakdown of the technicians employed by the Atomic Energy Authority.

| | |
|---|---|
| Biologists | 32 |
| Chemists | 863 |
| Geologists | 2 |
| Mathematicians | 239 |
| Physicists | 990 |
| Metallurgists | 275 |
| Chemical Engineers | 113 |
| Civil and Structural Engineers | 184 |
| Electrical Engineers | 505 |
| Mining Engineers | 1 |
| Mechanical and other Engineers | 1,014 |
| Holders of BSc(Tech) | 5 |
| Total qualified | 4,223 |

## *Radiation Monitoring ...*

Monitoring of food, air and water for radioactive contamination, by local medical officers of health was the subject of a question put to the Parliamentary Secretary of the Ministry of Housing and Local Government, **Sir Keith Joseph,** by **Mrs. Butler** (L., Wood Green). She asked if the Minister had replied to local authorities who had requested permission to carry out such monitoring, and would the Ministry undertake to notify medical officers of health of all possible sources of contamination in their area. Sir Keith replied that the suggestion would duplicate the existing comprehensive monitoring arrangements at present carried out by the Government. Details of the location of radioactive materials were available to local authorities upon request, and if the Radioactive Substances Bill now under discussion in the Lords was passed, local authorities would be entitled, subject to national security conditions, to be sent copies of certificates of registration relating to premises in their area.

## *and Reactors for Spain*

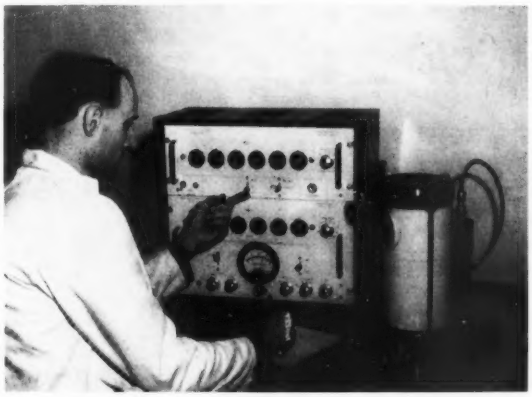
With the international air full of acrimony over the proposed German bases in Spain, it was refreshing to be reminded that Britain is in the market for the supply of nuclear reactors to that sunny land. **Mr. Noel Baker** (L., Swindon) would have liked the Foreign Secretary to propose to the Spanish Government that any reactors built by British firms be submitted for approval to the International Atomic Energy Committee, who would ensure that no fissile material was produced for military purposes. Mr. Lloyd considered the question hypothetical. So far as he was aware, no negotiations were being conducted for building any reactors in Spain. At this point **Mr. Woodburn** (L., Clackmannan and E. Stirling) neatly pointed out the paradox of the argument, which was that modern reactors automatically produce fissile material. Mr. Woodburn was more concerned with the dangers inherent in the production of such material by small countries who might act as suppliers for the larger nations, enabling those nations to get around any proposed agreements controlling the manufacture of plutonium and other products.

# Equipment and Materials

Items published in this monthly feature are compiled from manufacturers' current literature. Readers requiring further information should use the form at bottom of the page. Manufacturers are invited to send literature or details of their products for inclusion in this feature.

### Micro-Particle Counting

The SC/LP scintillation counter which is now being marketed by Panax Equipment Ltd., has been developed for the counting of millimicrocurie quantities of very low-energy beta-radiation emitters such as tritium and carbon-14. The counter is intended primarily for use with liquid phosphors but can also be converted to accommodate plastic phosphors and sodium iodide crystals. The equipment consists of a 1½ in. thick (minimum) lead castle fitted with a light-tight door which is interlocked with an EHT switch and a shutter assembly to protect the photomultiplier and to prevent external light increasing the background count. Normally, a standard 30 ml glass jar is used as a container for the liquid phosphor into which the radioactive source to be counted is placed; since the shutter provided opens automatically when the castle door is closed and operates a micro-switch, samples can be changed in normal room lighting while maintaining a low level of background counts. When in position in the castle, the bottom surface of the glass container is adjacent to the sensitive surface of the photomultiplier tube and a good optical contact is maintained by means of a liquid light guide. The shutter assembly can be replaced by a crystal mount which will accept 1½ in. diameter by 1 in. sodium iodide crystals or plastic phosphors of similar dimensions; by inverting the unit, liquid and solid samples can be investigated with minimum air gap between sample and detector. The high efficiency counting of low-energy beta-emitters in other forms can also be carried out with this equipment. For counting purposes, the counter is used in conjunction with a linear amplifier and suitable scaling apparatus incorporating discriminator and EHT supplies. Efficiencies of 10 per cent. for tritium and 50 per cent. for carbon-14 have been obtained at room temperature, but higher counting efficiencies can be achieved by cooling the castle in a standard refrigerator. **(AL 1)**



**The SC/LP scintillation counter which has been developed by Panax Equipment Ltd., for the counting of millimicrocurie quantities of very low-energy beta-radiation emitters**

### $\gamma$-Rays Measured

Looking like a white-painted bomb pointing skyward, 30 in. high and 9 in. in diameter, the Gammagraph, Model 65A, developed and manufactured by Electronic Instruments, Ltd., of Richmond, Surrey, is designed for accurate and continuous measurement of gamma radiation in or out of doors. Powered by an ordinary motor car battery and fully weatherproof, the Gammagraph can work in isolated country places far from main electricity supplies. It is completely mobile. It can be put in a car or van so that a rapid survey of gamma radiation can be swiftly made over a wide area should there be, accidentally, a rise in radioactivity in the atmosphere. It is a ruggedly constructed recording radiation dose-rate meter. Three preset ranges enable accurate records to be kept of gamma radiation levels from natural background up to 10 mr/hr. It consists basically of an ionization chamber, 18 in. long, containing a special mixture of gases under pressure, mounted vertically on a hermetically sealed case containing the electrometer circuits and a clockwork-driven recorder. The recorder trace can be observed through a glass panel without opening the instrument and all controls are mounted internally to avoid unauthorized interference. Power for one month's continuous operation is provided by a conventional 12v, 40 ampere/hr car battery. Except for one electrometer valve, the circuit is fully transistorized. **(AL 2)**

### Swiss Betatron

Suitable for the non-destructive testing of very thick materials, and for research with high energy X-rays and electrons is the 31 MeV betatron made by Brown Boveri & Co., of Switzerland, and marketed in the United Kingdom by Watson & Sons (Electro-Medical) Ltd.—Industrial Division. Steel can be radiographed up to a thickness of 20 in. At full output and focus to film distance of 2 m, radiographs of 8 in. of steel can be obtained in 4 min with a

Cut along here

**To: NUCLEAR ENERGY**

**147 Victoria Street, London, S.W.1**

*Please send further details of the following items in the* EQUIPMENT and MATERIALS *feature for April, 1960*

*Item No's* ..... ..... ..... ..... .....

..... ..... ..... ..... .....

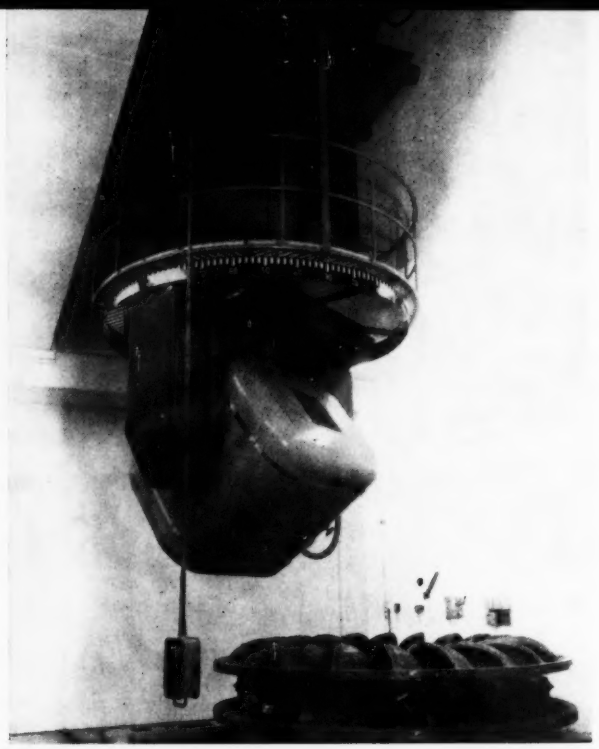
**IS THIS ENQUIRY CONFIDENTIAL?** YES | NO

*Enquirer's Name* .....

*Position* .....

*Firm* .....

*Address* .....

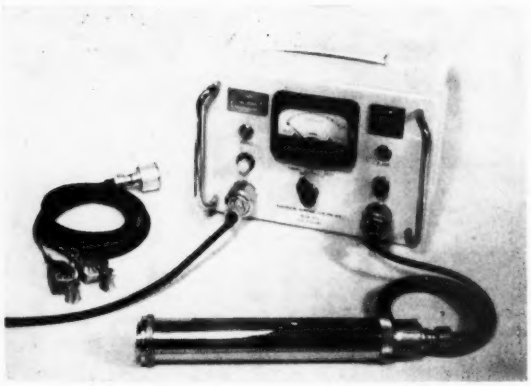


**Brown-Boveri 31 MeV betatron installation**

density of two, and in 30 min with 12 in. of steel. The instrument has two focal spots, each 0.1 mm × 0.3 mm. The wire penetrameter (DIN) sensitivity over a thickness range of 6 in.-14 in. of steel is almost constant at 0.3 per cent. At 10 in. steel a 0.03 in. diameter wire can still be seen. The very small focus size allows X-ray magnification to be used, and thus further improvement in sensitivity can be obtained. The apparatus can also be used for nuclear physics studies, including photo-nuclear reactions and generation of Cerenkov radiation. It has been used to study biological processes induced by high energy X-rays and electrons as occur, for example, in therapy and genetic changes. A betatron producing electrons and X-rays up to 35 MeV is available for cancer therapy. A detachable beam equalizer may be used and provides a beam of intensity constant to within ±5 per cent. over a circle of 8 in. diameter at 1 m from the target. The dose measured with a thimble chamber surrounded by 3 mm of lead is at least 62 rev/min at 1 m distance. Shutters in each beam control the beam height. For setting-up purposes, two light beams are projected along the centres of the X-ray beams. The targets are 531 mm apart and produce X-ray beams converging to a point at 2.4 m distance. They may be used separately or simultaneously. In the latter case, two parts of a specimen are radiographed producing a double field, or stereo radiographs may be made. A control desk contains sequence switches and a delay timer for controlling the magnet field, electron injection and orbit expansion. Ion chambers are fitted in the betatron head in each beam, and the dose rate and dose are indicated for each on separate meters on the control desk. The exposure may be terminated by the dosemeter (0-10,000 rev) or a timer (0-55 min). Power consumption is 16 kW and cooling is by a built-in fan. **(AL 3)**

### *Plutonium Detector*

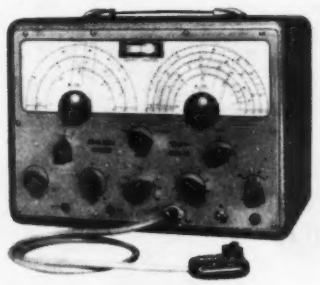
To detect plutonium at maximum permissible body burden level or even less, Plessey Nucleonics Ltd., have developed a mains or battery operated portable detector, the PNI 1080. This instrument is essentially a detector of low energy gamma radiation. As well as being capable of detecting minute amounts of plutonium-239 in the human body, with slight modification and recalibration the instrument can also detect the presence of americum, a radioactive substance which will be contained in the plutonium manufactured by reactors in this country. With another slight modification, the 1080 can detect uranium-235 which also emits low energy gamma rays. Yet another possible use of the instrument would be in the detection of plutonium-239 after a nuclear weapon accident. The complete equipment consists of a detector probe connected by up to 6 ft of cable to an indicating unit. The probe consists of a thin, thallium activated, sodium iodide scintillator mounted on the end of a multiplier photo tube. A chain of resistors is mounted on the inside of the probe in order to provide the correct potential on the dynodes and a cable matching network ensures optimum signal pulse transfer from the probe to the indicator unit. For hospital use the probe may be enclosed in a polythene container. The indicator unit of the PNI 1080 consists of a pulse amplifier, a pre-set but adjustable single channel pulse amplitude analyser, a variable and stabilized EHT supply for the photo tube, and a display system. All circuits in the indicator unit use transistors. Sensitivity of the instrument for direct plutonium radiation is 15 c/s/microcurie and about 0.2 per cent. of this figure for background radiation. Maximum permissible body burden of plutonium located at one point gives about five times the background count through 1 cm of human tissue. **(AL 4)**



**Low energy gamma emission detector manufactured by Plessey Nucleonics Ltd**

### *Signal Generator*

Taylor Electrical Instruments Ltd., Slough, have introduced a new AM/FM signal generator with sweep and crystal calibrator, designed mainly for the servicing of AM and FM high frequency receivers and the intercarrier IF stages of television receivers. The 61A as it is called, provides, in conjunction with an oscilloscope complete facilities for the sweep alignment of the RF, IF and discriminator or ratio detector stages of AM and FM receivers. The generator covers the range 4-120 M/c 5 bands, all on fundamentals. Calibration accuracy is ± 1 per cent. Modulation is 35 per cent. at 400 cycles. The FM and sweep section also operate on fundamentals, avoiding the confusion and poor frequency accuracy inherent in the frequency difference method. The FM and sweep bans cover the frequencies 4-12 megacycles and 70-120 megacycles in three bands. Calibration accuracy of the FM generator ± 2 per cent. The AM generator may be used as a marker during sweep alignment. A variable phasing network is incorporated and retracing blanking is provided. **(AL 5)**



**Taylor's AM/FM signal generator**

# Book Reviews

**Nuclear Technology for Engineers,** by R. Hobart Ellis, Jr. Published by McGraw-Hill Publishing Co., Ltd. Size 9 in. × 6 in. × 280 pp. Price 74*s.* 0*d.*

This is a further volume in the McGraw-Hill series in nuclear engineering, a series which includes several specialized and some general introductory books. This volume is in the latter category, as it describes a very wide field including tracer techniques, irradiation technology and fission and fusion reactors. The aim is presumably a book for the general engineer who wishes to inform himself about the new techniques available. The necessary and laudable process of transferring such techniques from the laboratory into general engineering practice is helped by such books as this, though anyone seeking to design for or even to assess practicability of a particular application will have to refer to far more specialized sources. There is a dangerous tendency to present a simplified picture of phenomena, without even stating that the picture is simplified. A reactor engineer might expect a book with this title and in this series to be mainly about reactors. However, the emphasis given in the book is appropriate on the broad view that a typical engineer is more likely to need to know the possibilities of radio-isotope and irradiation techniques than to know the nuclear problems of reactor design. The main content of the book lies in its central half, which deals with the use of radio-isotopes in such applications as tracer work and density gauging and the use of large doses of radiation in such applications as food sterilization and chemical catalysis. Chapters are included dealing with radiation detectors and dosimetry and high power sources of radiation. Some engineering applications are described though the tendency is towards description of laboratory techniques and laboratory instruments. There is very little mention of health physics. The treatment should enable the reader to make a preliminary assessment of the likely value of the new techniques. In assessing feasibility within a given time, he should take note of which diagrams refer to existing plant such as linear accelerators and which refer to plant still in the "conceptual design" stage, presumably requiring many years of development. The introductory chapters on atomic and nuclear physics are mainly simple and clear. However, the author separates the description of radioactive decay into its two phases of particle emission and gamma decay of the metastable daughter nucleus. This leaves the reader in doubt for several pages as to whether the two phases are separated by an appreciable time interval. Mathematics is so strenuously avoided that even the differential equation for simple decay is treated as difficult. There are a few misprints. The concluding chapters on fission and fusion reactors are descriptive and very compressed, so they contain little information to help a reactor engineer. The liquid drop model of the nucleus is described, including all five terms of the expression for the binding energy and all terms of the four factor equation are defined, but the occurrence of fast neutron fission in uranium 238 is not mentioned. In view of the mathematical standard adopted, it is perhaps surprising that the neutron diffusion equation is stated and that an attempt is made to develop a quantitative treatment of the dynamic behaviour of fission reactors. The resulting picture of reactor behaviour is very simplified and should be described as such. Various types of fission reactors are surveyed, including several liquid fuel reactors, but the problems of corrosion, so important for these designs, are not mentioned. The chapter on fusion reactors briefly describes the reactions considered and the outlines of the main American experiments roughly as they were described at Geneva in September, 1958.

M. G. COOPER
*Cambridge University.*

**Nuclear Ship Propulsion** by Holmes F. Crouch. Published by Cornell Maritime Press, Maryland. Distributed in United Kingdom through Putnam & Co., Ltd., London. Size 6 in. × 9 in. × 348 pp. Price 87*s.* 6*d.*

For the engineer of whatever category who is seeking some guidance to what nuclear engineering and its potentialities are all about, *Nuclear Ship Propulsion*, by Holmes F. Crouch, is really worthwhile. It contains a substantial foundation to this new subject which will ultimately be the crowning achievement of so many departments of learning from theoretical physics to the biological sciences. All marine engineers who make the grade are knowledgeable individuals but when they become nuclear marine engineers they will need more than a nodding acquaintance of many regions of applied science. It is evident from this work that the author is at home both in the marine field and in atomic physics. He is a Commander in the U.S. Coast Guard Reserve and at the same time has had years of experience in nuclear energy research. The forthright and practical approach to the subject will appeal to readers who are not too happy with abstruse higher mathematics that are so often associated with the nuclear energy world. In fact the author has cut advanced theory to the minimum and has succeeded in presenting the subject in a way that is at once solid and intelligible. Indeed a person who knows next to nothing about nuclear energy will profit from this volume and at the same time the expert will see numerous references for those seeking more advanced study. A wide field is covered, wisely beginning with a discussion on the similarities and differences in sources of energy, the fuel oil of the conventional ship being replaced by a "capricious solid metal" in the nuclear ship. Marine engineers will welcome the chapters on the diversity of fuel forms, removal of heat, fuel calculations, ship reactors, notably the *Savannah* reactor features and gas reactor turbines. Shielding considerations, design safety, health physics and the like are also discussed in a practical way and the author has some sensible observations on the future for nuclear merchant ships. Shipbuilders will hope that the author is right in expecting considerable ship replacements in 1960-70, although there is really little sign of that at present. It is certain, however, that in that decade a number of nuclear merchant ships will be built. How many is anybody's guess but this book will deserve a place in the library of any ship and anyone interested in the future of the sea and ships.

D.S.W.

**A Simple Approach to Electronic Computers,** by E. H. W. Hersee, MA. Published by Blackie & Son Ltd. Size 7½ in. × 5 in. × 105 pp. Price 12*s.* 6*d.*

I found this a rather unsatisfactory book. For one thing, the author claims it to be a *simple* approach to the subject. My own feelings are that without a basic knowledge of the subject this book could convey to the novice an over-simplified and, therefore, erroneous impression of electronic computers, which is as misleading in its way as is the nonsense the author is anxious to dispel. Further, it is my contention that if a mere 100 pages are to be allocated to a subject upon which many large volumes have already been written, the author would have been better advised to content himself with overall principles rather than become involved with the logics of but a few of the basic working principles. So much has been left unsaid that I am inclined to doubt the value of this publication.

R.L.S.

**Aluminium Busbar,** by A. G. Thomas and P. J. H. Rata. Published by Hutchinson & Co. (Publishers), Ltd. Size 9¼ in. × 6¼ in. × 106 pp. Price 21*s.*

Published for the Northern Aluminium Co., Ltd., this book makes out a convincing case for the use of aluminium and aluminium alloys for busbars. Information is given on the design, construction and installation of aluminium busbars and all in all the book provides an extremely useful handbook on this subject. There are plenty of tables, graphs and diagrams and three or four well-placed half-tones.

### Other Books Received

**Towards a New Energy Pattern in Europe.** Published by the OEEC. Size 6 in. × 9½ in. × 126 pp. Price 9*s.* 0*d.* Report on the Energy Advisory Commission of the OEEC led by Professor Austin Robinson.

**Health Physics in Nuclear Installations.** Published by the OEEC. Size 6 in. × 9½ in. × 410 pp. Price 37*s.* 6*d.* The proceedings of the Symposium on health physics organized by the European Nuclear Energy Agency at the Danish Atomic Energy Centre, Riso, May 25th-28th, 1959.

**The Industrial Challenge of Nuclear Energy III—Stresa Conference. Part 2: Atomic Law and Administration.** Published by OEEC. Size 6 in. × 9½ in. × 264 pp. Price 18*s.* 6*d.* Proceedings of Sessions I, IV and V of the 1959 conference on industry and nuclear power at Stresa.

# PEOPLE... in the NUCLEAR NEWS

**MR. JOSEPH SAMUELS,** who, as a member of the board of Winston Electronics Ltd., has been purchasing director for several years, has now been appointed works director in charge of production. Mr. Samuels, who is 49 years old, was educated at St. Mary's College and the Imperial College of Science and Technology, London. Before joining Winston Electronics in 1954, he was for several years with Standard Telephones & Cables and later Sunvic Controls. He joined the Winston board in 1956.

The appointment last autumn of **CAPTAIN R. A. VILLIERS,** CBE, AMIEE, RN(Retd), as the first director of the Scientific Instrument Manufacturers' Association of Great Britain, was the major step in the administrative reorganization of SIMA and the beginning, also, of a new era of expanding activities, increased national and international effectiveness and a serious drive for increased membership. To facilitate this aim, **MR. G. L. KNIGHT** has been appointed assistant to the director of SIMA. Mr. Knight, born in 1929 in Portsmouth, was educated at Winchester Choir College and Wells Cathedral School. After a short teaching career, he was called up for National Service and served in the Educational Corps. On leaving the Army, he served for a time in a bank and then left to join the Fleet Air Arm of the Royal Navy on a short-service commission. He will operate under Captain Villiers in the field of information and external activities in particular, and will also be responsible for the collection and distribution of information for SIMA.

**SIR JOHN WRIGHTSON,** Bt. is the new chairman of Head Wrightson & Co., Ltd., following the retirement of **MR. RICHARD MILES,** who had held the position for ten years. Sir John and Mr. Miles were joint managing directors, Mr. Miles having been a managing director for 25 years and Sir John for 10 years. Sir John continues as sole managing director.

New directors appointed to Thorium Ltd., following its acquisition from Imperial Chemical Industries Ltd., and Howards & Sons Ltd., by Rio Tinto and Dow Chemie AG include **MR. R. W. WRIGHT** (chairman), **MR. J. R. POOLE, MR. J. R. ROBINSON** (nominated by Rio Tinto), and **MR. C. BENSON BRANCH, MR. R. H. GREGORY,** and **DR. J. D. HEAD** (nominated by Dow).

Recent visitor to the Atomic Weapons Research Establishment, Aldermaston, was **LORD HAILSHAM,** the Minister for Science. With him was **MR. F. F. TURNBULL,** secretary of the Office of the Minister for Science. They were accompanied by the chairman of the UKAEA, **SIR ROGER MAKINS,** the Member for Weapons Research & Development, **AIR CHIEF MARSHAL SIR CLAUDE PELLY,** and the director of AWRE, **DR. N. LEVIN.** During his tour of the Establishment, Lord Hailsham saw particle accelerator machines, including the new Van de Graaf accelerator, in the Nuclear Physics Division. The visit was one of a series undertaken by the Minister to establishments of the UKAEA.

**DR. ALBERT C. HALL,** director of research and engineering for The Martin Co., U.S.A., has been appointed the company's vice-president of engineering. Since joining Martin in 1958, Dr. Hall's major effort has been with the TITAN programme. Martin is principal contractor for airframe design, fabrication and testing of this weapon system.

**MR. BARRIE HEATH,** DFC, MA, managing director of Powell Duffryn Carbon Products Ltd. and a director of other companies in the Powell Duffryn Group, has relinquished his Powell Duffryn appointments to take up another post. **MR. R. TURNER,** MIMechE, acting managing director of Powell Duffryn Technical Services Ltd., has joined the board of Powell Duffryn Carbon Products Ltd., as deputy chairman, and **MR. F. W. STOKES,** a director and the works manager of the company's factory at Hayes, has been appointed general manager.

Hagan Controls Ltd.—one of the Plessey Group of companies—announce that **MR. K. R. SANDIFORD,** BSc(Eng), has joined the company as general manager. Since 1954 he has been chief instrument engineer of the development and engineering group of the UKAEA. During the 1939-45 war Mr. Sandiford was responsible for the production of fire control instruments for British coastal artillery.

## Experimental Studies of NATURAL CIRCULATION BOILING

### *Supplementary References to article appearing on pages 156-159*

**Further References**

*The following literature was also referred to in a more general way and will provide readers with useful sources of information.*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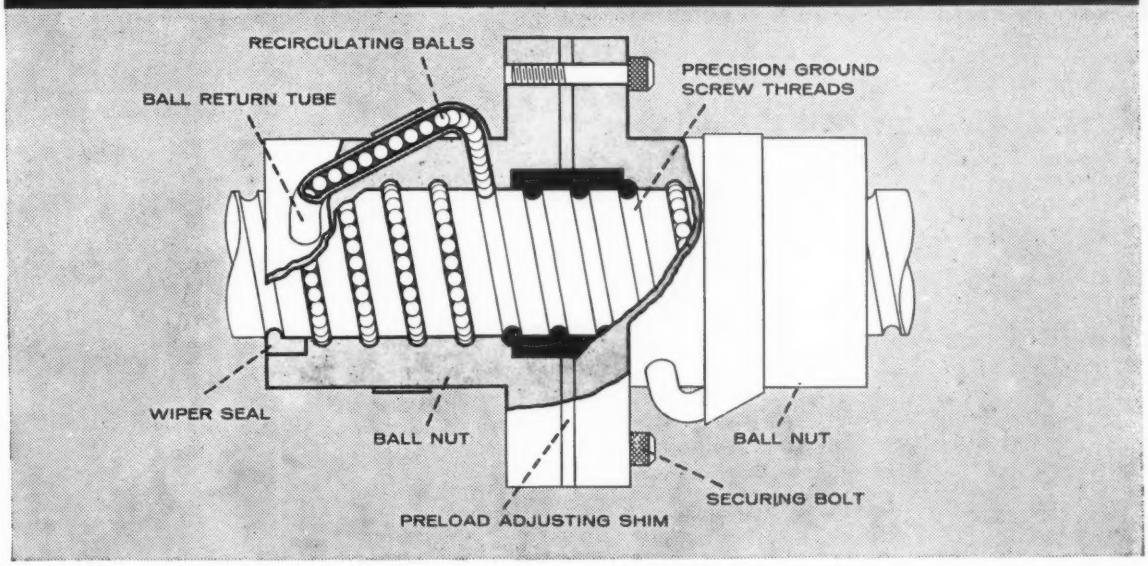


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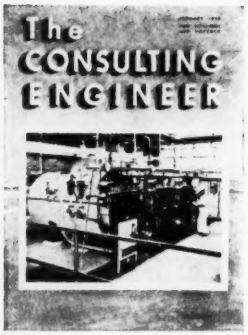


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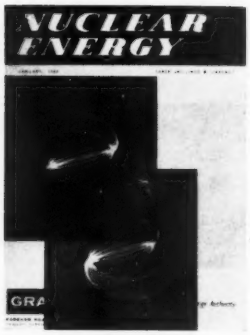


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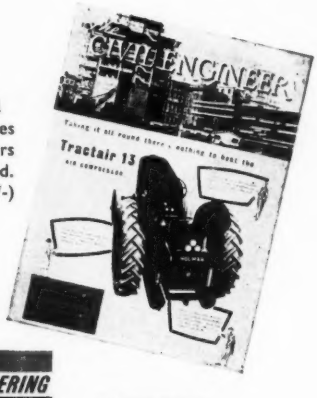


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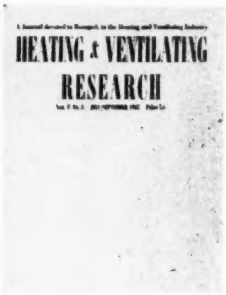


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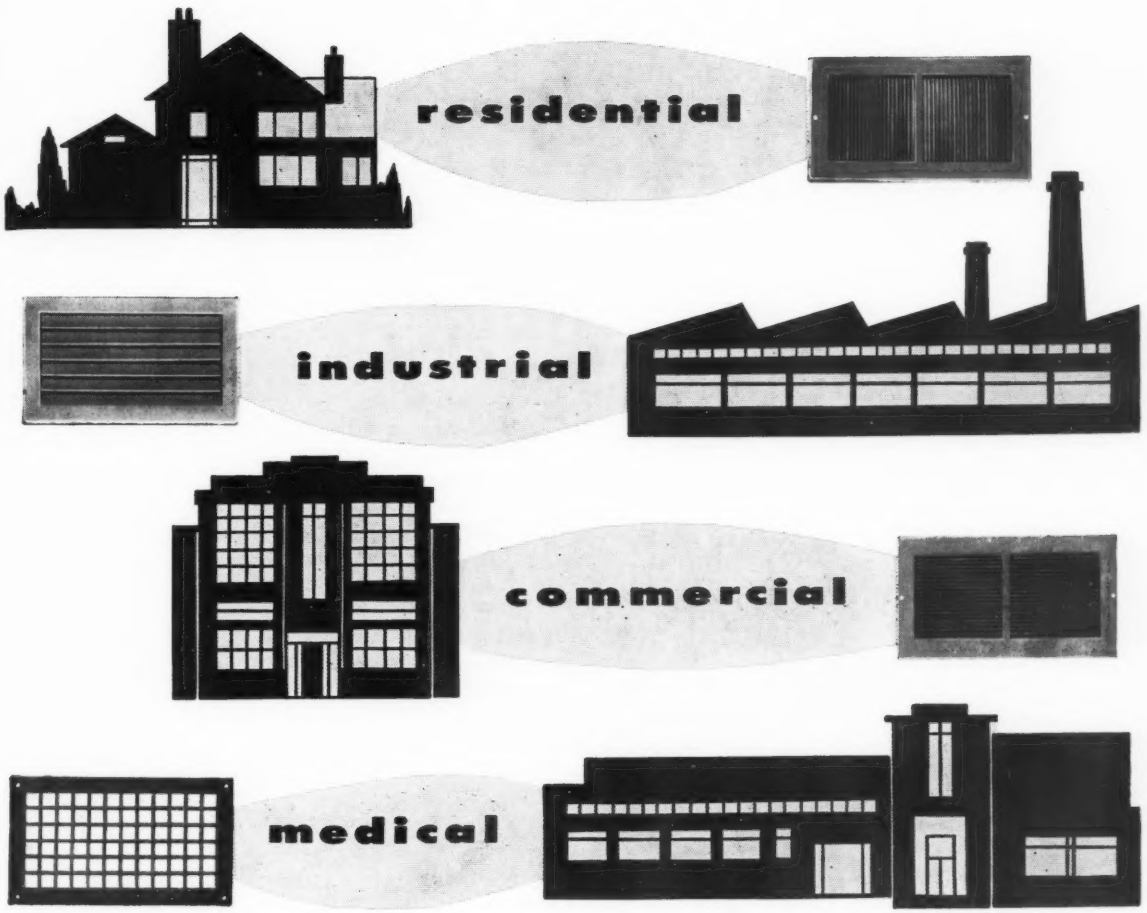


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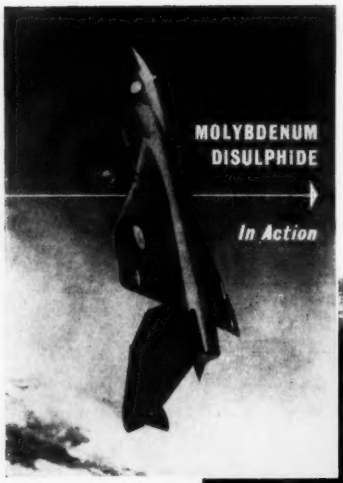

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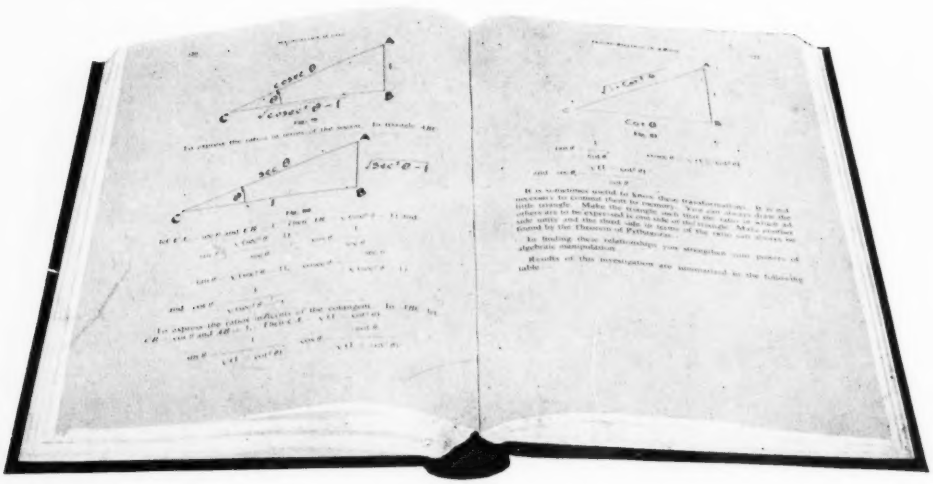

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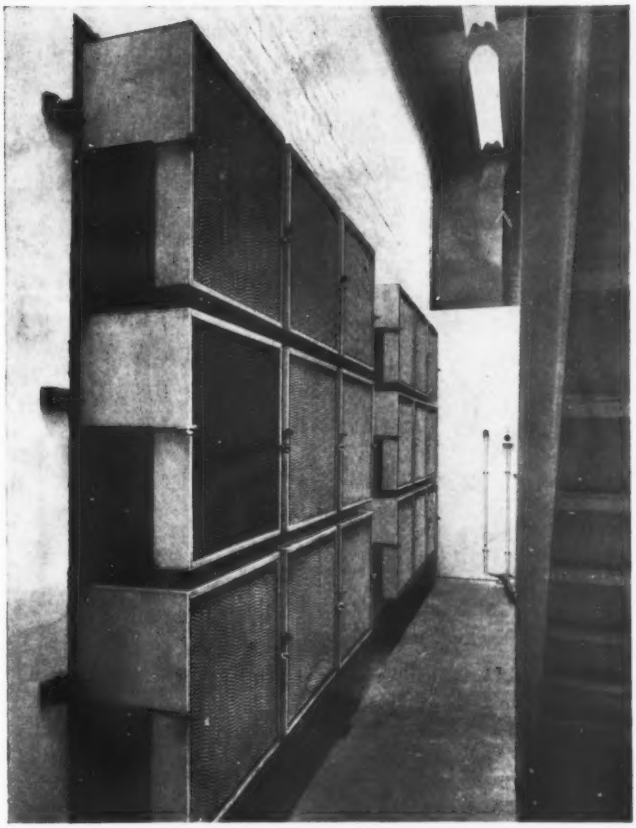

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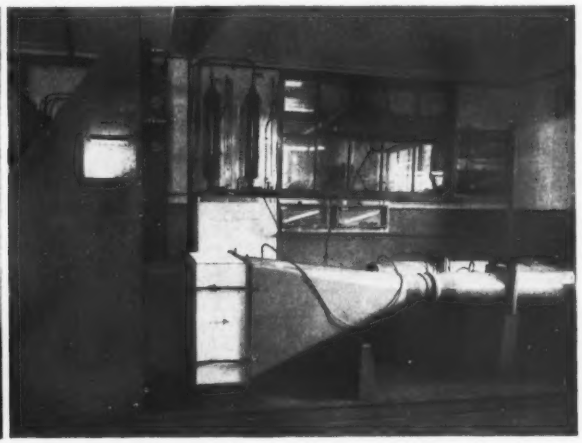

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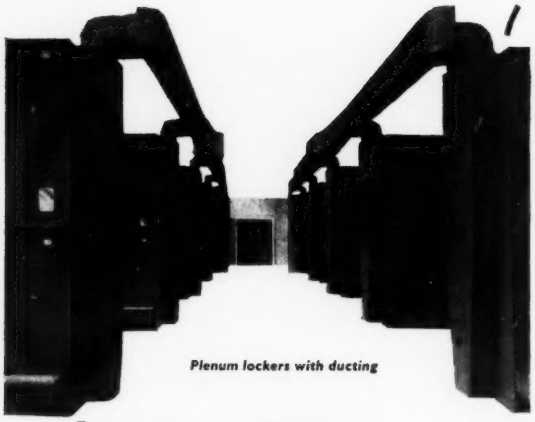

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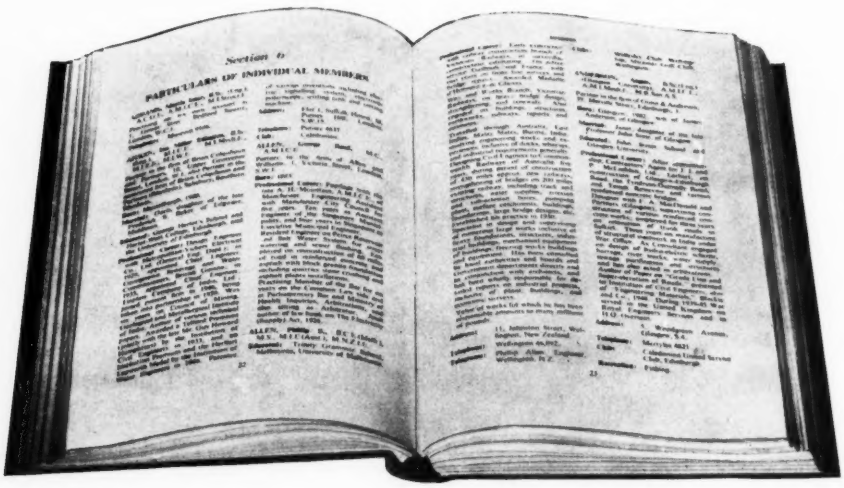

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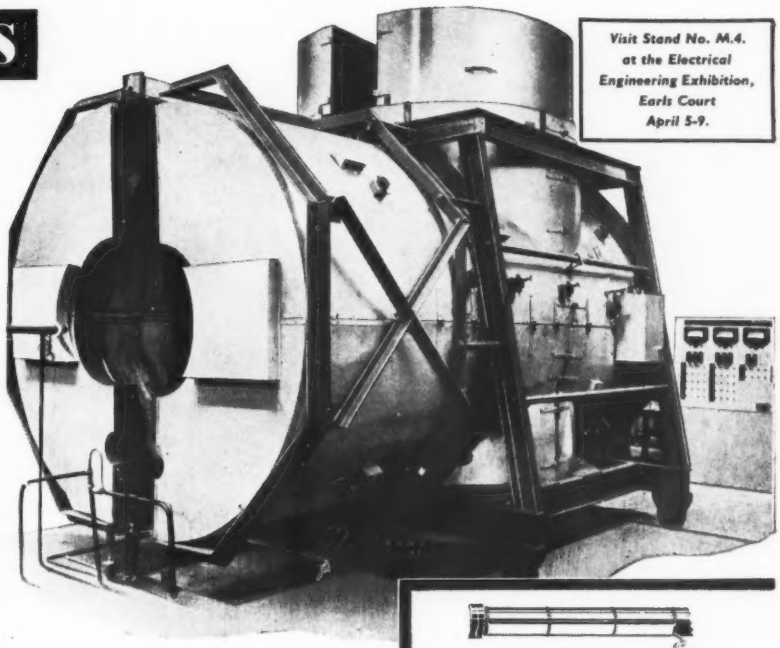

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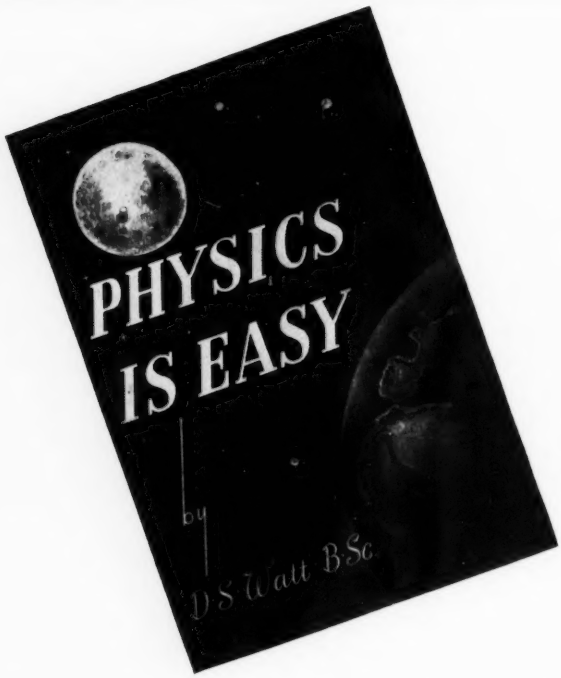


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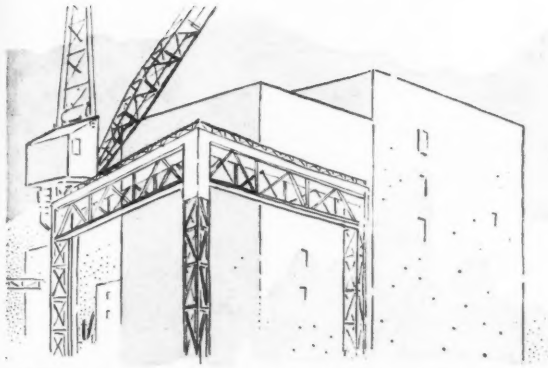

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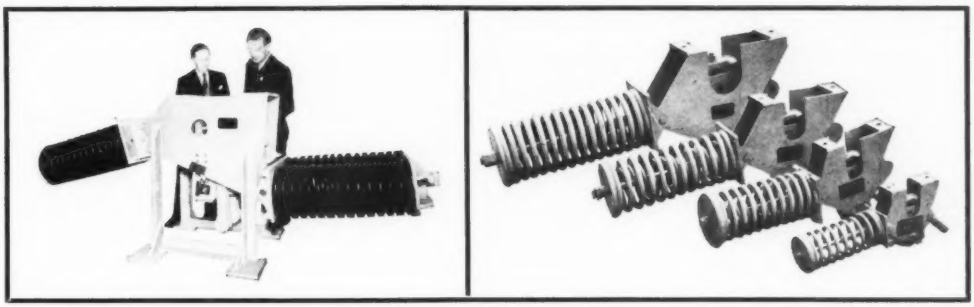

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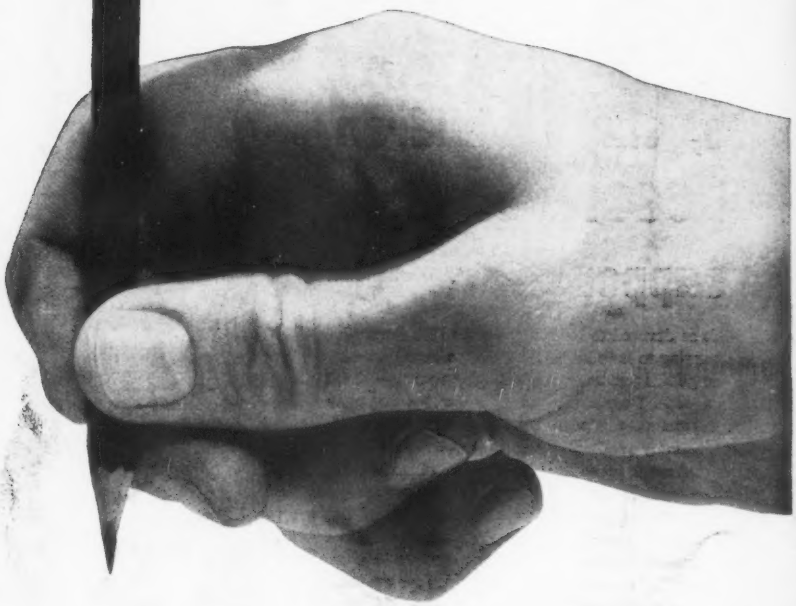

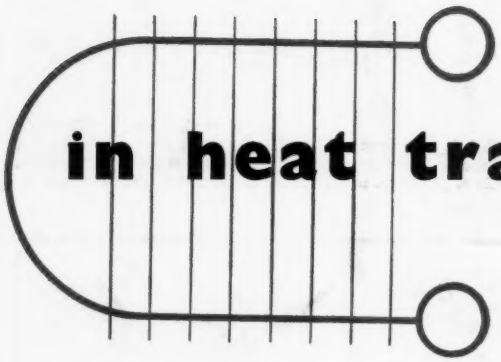

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For all systems, using steam or hot water.

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Brine, Chilled Water and Direct Expansion Refrigerants including coils for Solvent Recovery.

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A wide range of standard models, covering small and large air-flows.

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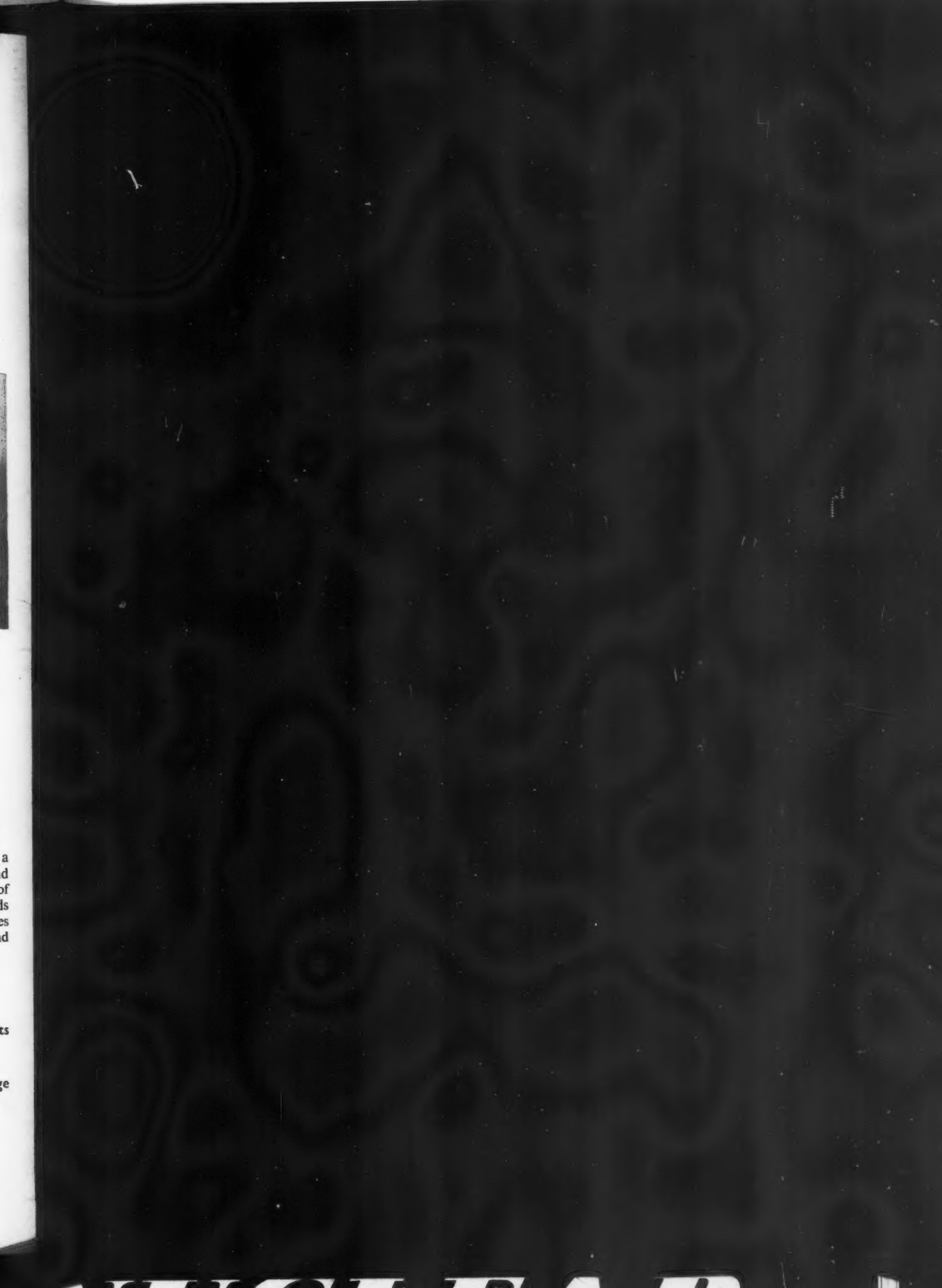
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